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ELECTRICAL INSTALLATIONS

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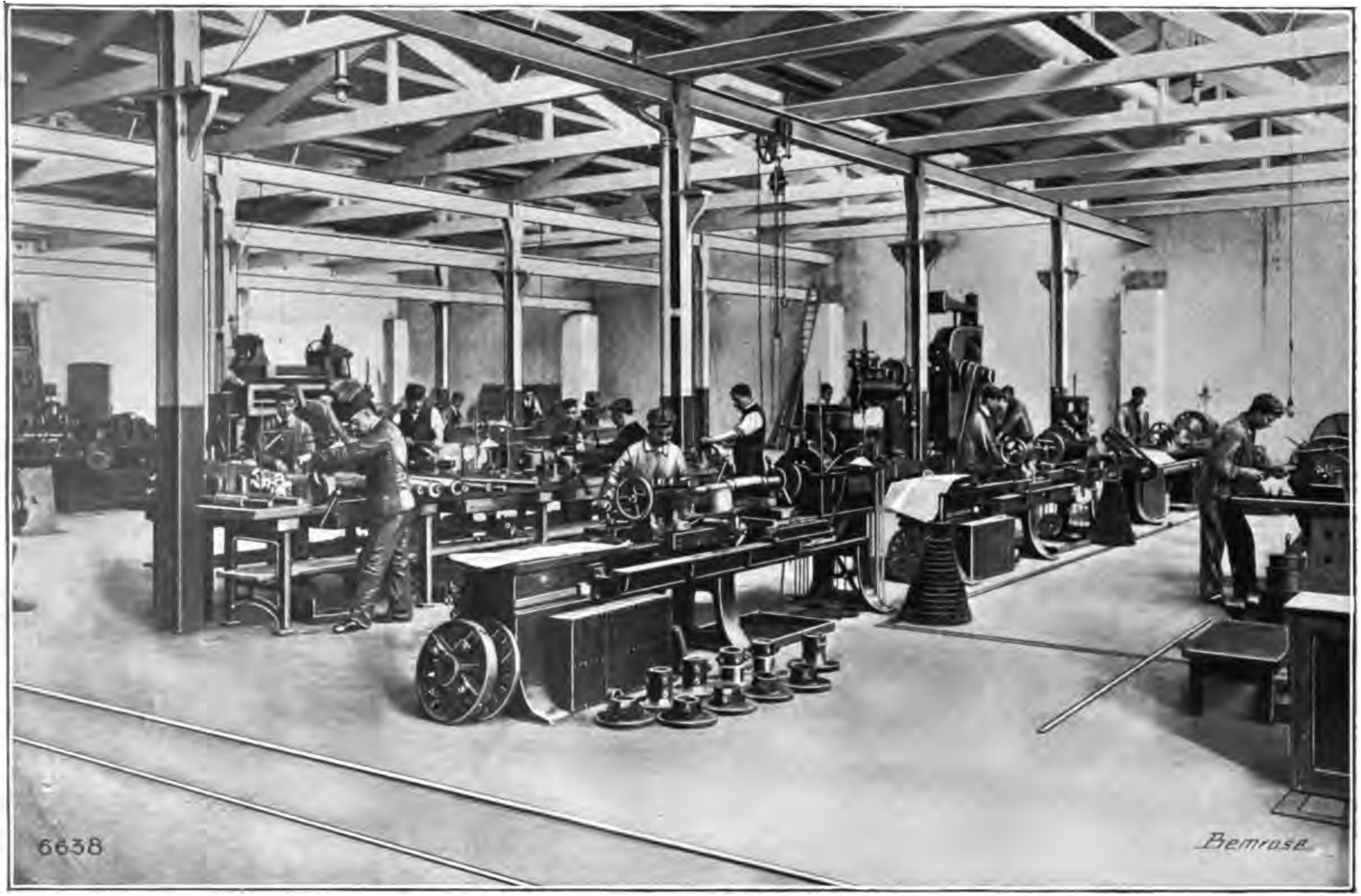

Electrically-Driven Machinery as it Should Be

Frontispiece

ELECTRICAL INSTALLATIONS

OF

ELECTRIC LIGHT, POWER, TRACTION AND INDUSTRIAL ELECTRICAL MACHINERY

BY

RANKIN KENNEDY, C.E.

AUTHOR OF "ELECTRICAL DISTRIBUTION BY ALTERNATING CURRENTS," "PHOTOGRAPHIC AND OPTICAL ELECTRIC LAMPS," AND NUMEROUS SCIENTIFIC ARTICLES AND PAPERS

WITH NUMEROUS DIAGRAMS AND ILLUSTRATIONS

VOL. IV.

MECHANICAL GEARING; COMPLETE ELECTRIC INSTALLATIONS;
ELECTROLYTIC, MINING, AND HEATING APPARATUS;
ELECTRIC TRACTION; SPECIAL APPLICATIONS
OF ELECTRIC MOTORS

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PREFACE TO VOL. IV

This volume discusses the more complete installations for electric light and power transmission. With the exceptions of electrolytic and electro-thermal installations, electricity acts merely as a carrier or transmitter of the power of prime movers to some work to be done: and hence so long as the method for the production of electrical energy from fuel is the only commercially successful one, the prime mover remains the most important element in the complex system. Its economy in fuel, and also the nature of the fuel it can utilise, is the engineer's chief concern; hence installations from the engineer's point of view are discussed under the classification to which their fuel belongs. It is a secondary question whether the installation supplies the energy as a continuous current or as alternating currents. It is necessary, however, to notice the cases in which the one has more advantages than the other, for neither is universally applicable.

The importance of the transmission of power in works from prime mover to machines cannot be too strongly impressed. It is not merely by the substitution of a prime mover by an electro-motor that much advantage is to be gained, but by the abolition of shafting, pulleys, belting, and gear wheels for transmitting the power; these have their legitimate functions in the machines to which electro-motors are attached, the power being distributed among the machines by electric conductors. This being impressed upon power users, they can readily realise the true position and functions of the dynamo-electric machine and electric-motor in an installation.

In heat installations, wherein high temperatures are produced electrically, it must not be forgotten that it may be necessary to generate the electrical energy from a heat engine and dynamo, in which case only a very small fraction of the heat of the fuel will be recoverable as heat from the electricity, so that only in exceptional cases can these processes be commercially successful.

The thermopile has been briefly alluded to, not that it is at present of much value, but that it has possibilities in view of the low efficiency of heat engines generally.

Electrolytic installations are, beyond the generators and instruments, of little interest to ordinary electrical engineers. Being chiefly the chemist's concern, we have not taken up the examination of the chemical operations, apparatus, or products in these installations. Similarly in electric traction, the electrical portions only are considered; the whole subject of traction is three-fourths purely mechanical engineering. Mining and miscellaneous installations conclude the book, with a brief discussion on underground main wiring.

Heavy electrical engineering only has been treated in this work. Telegraphs, telephones, signals, and other electrical apparatus of the smaller and lighter branches are of equal interest to a different, but no less important, class of electrical engineers from those engaged in electric light and power work.

These subjects, including Wireless Telegraphy, X-Rays, Medical and Surgical Apparatus, are to be fully treated in a fifth volume now in preparation, so that these subjects may be brought up to present-day theory and practice in a separate book.

Whatever may be the fate of the prime mover-cum-dynamo-electric generator in the future, the electric-motor has come to stay. The discovery of a more direct converter of fuel energy into electrical energy would immensely increase the demand for electric-motors and so would compensate for the disappearance of the dynamo from fuel-fed generators. This development in generators is the only one to be expected in the future.

Further improvements in obtaining light from electricity are bound to be made, the present lamps being far from economical; the Nerust and Hewitt lamps are steps in that direction.

The great question of storage in connection with electricity supply stands pretty much where it did ten years ago, with the exception of Mr. Edison's new cell, in which the use of strong materials and alkaline solutions replace lead and acid, raising our hopes for some substantial improvement in this direction.

Finally, the author trusts that the volumes will be found useful to active electrical engineers and others engaged in the great work of extending the use and benefits of the improvements to be obtained by the proper selection and operation of modern electrical machinery.

My thanks are again due to the many firms who kindly lent illustrative blocks and gave much useful information, and also to the publishers for the excellent appearance of the volumes, in printing, illustration, and binding.

RANKIN KENNEDY.

Leeds, *March* 1903.

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ELECTRICAL INSTALLATIONS

CHAPTER I

GEARING

THE electrical engineer should avoid the use of gearing, such as belts, wheels, shafts, pulleys, ropes, and the like, as much as he possibly can: the power required to drive and keep in motion all these sort of things is absolutely dead loss. It is by using electromotors close up to the working machinery that the electrical engineer can offer the very best system for transmitting power from a prime mover to machines distributed throughout a large mill or factory.

A prime mover such as a steam-engine may be made highly efficient by adopting every refinement of steam engineering, and many beautiful examples may be seen in large mills in which much has been expended to reduce the steam consumed per indicated horse-power, but very little has been done to economise the power so produced—huge shafts, ropes, and belts are frittering away from 50 to 75 per cent. of the power of the splendid giant labouring in the engine-room. It says little for the energy and enterprise of the present-day electrical engineer when at this date such an antiquated and rude system of distributing power from an engine as that by pulleys, ropes, belts, toothed wheels, and shafts, is still actually adopted, even in new works in Britain, at a date when the electrical system has been proven over and over again to be far superior. We talk much of educating the engineer, while as a fact it is the power user who ought to be educated for his own benefit, so far as to enable him to see what great electrical improvements are available for his use.

In previous volumes brief references have been made to the large distribution schemes for supplying electrical energy for power, the promoters thereof hoping that power users will throw out their huge engines and boilers and put in electrical motors instead, and take the energy required from the large system of supply. But a mill or works owner has several alternative schemes to consider, schemes to which more detailed reference will be made later on. First, he may cast aside his engine and boiler and put down one or more large motors, only leaving his mill gearing as before: in this case nearly all the waste and losses of power will go on in the gearing just as before, and the power will in all probability cost more than it did with the engine and boiler.

Secondly, he might keep his engine and boiler and drive an electric generator direct with it, and from that drive by motors throughout the mill.

Thirdly, and by far the best system, whether the electrical generator is on the spot or the supply taken from a company, is to clear out all gearing and put motors on each machine as direct as possible. This is the only way to realise the full benefits of electrical transmission of power.

The promoters of the large-supply schemes will find to their cost that it is not the trouble and cost of producing electrical energy that deters power users from adopting electrical transmission. It is the knowledge of the fact that only by a complete reconstruction can an established factory make the change so as to obtain the full benefits, and even those who have made the change can in most cases generate the energy by their own steam plant cheaper than any supply company, especially for large powers. The main question is not at all whether to abandon the steam-engine and boiler or not. The question is whether to abolish all the gearing in the factory and adopt motors throughout, and the backward state of electrical transmission among power users is chiefly due to the want of knowledge of the advantages of this system, and also to the large first cost of the numerous small motors required to carry the system out properly in practice. The want of knowledge is being filled up gradually. The production of small motors at reasonable prices is a problem the solution of which is being evolved.

The small motor might be cheaper if not for the absurd restrictions of fire-office rules about enclosing them. It is surprising to find a large industry submitting to the dictation of ignorant officials in purely technical matters, and obeying rules which the most ordinary common-sense proves to be unnecessary. The trade should surely be powerful enough to remove these stupid restrictions. Another cause of high cost is within the control of the makers themselves to some extent. and that is the standardisation of motors. It is a bit late to begin, now that the short-sighted municipal engineers have fixed upon diverse pressures, instead of all agreeing to one common pressure. The pressures are, however, for small motors between 200 and 250 volts, and one winding at different speeds may be used on these municipal supplies. Municipal supplies are not, however, able to supply electrical energy as cheaply as it can be made by the power user on the spot.

Electric Power Transmission

This has been proved over and over again. In a recent case, for example, in 1889, an installation in a new factory to be entirely lighted and driven by electrical energy was fitted out. From then till now it has run continuously with one boiler and two engines and dynamos, ten motors and about 800 lights, and strict accounts have been kept of all costs, interest on outlay, depreciation, and everything for twelve years.

The firm is now moving into a much larger factory, and of course electric light and power are to be provided again. A careful inquiry into the costs of production of one unit by the isolated plant during a period of ten years proved that, taking everything into account, the unit cost 1.2 pence for power and light taken together, while the municipal supply cost 1.5 pence for power and 4 pence for light—prices which of course decided the matter in favour of a plant generating on the spot, saving at least £250 per annum.

The fact of the matter is, that any consumer who requires 100 K.W. supply and over can obtain it at less than one penny per unit with his own plant, if that plant is properly chosen, laid out, and worked.

Meanwhile the point of importance is that a supply of energy delivered in bulk to a consumer for power purposes must be nearer a halfpenny per unit than a penny, and then it will be of little advantage if the "one machine one motor" principle of transmission is not adopted throughout.

The day of the big engine or motor distributing power by belts, pulleys, shafts, and ropes is past. Still these gears have a very large field of usefulness within the mechanism for transmitting power from shaft to shaft, and for speed changing. This use is the legitimate use of gear wheels, belts, &c. That is, in the machinery itself, hence a brief discussion of various gears is necessary in a work for engineers. Motors must be connected by some gear to the shafts or machines to be driven.

The simplest and commoner gearing is belt gear. In most cases the speed of the motor is not the same as the speed of the shaft to be driven: gearing is therefore necessary for this reason if for no other, and a belt and a pair of pulleys offer a ready means.

Mr. John Tullis of St. Ann's Leather-Works, Bridgeton, Glasgow, an eminent authority on belts, has given some valuable information in a paper before the West of Scotland Technical College, from which some extracts are here given.

The observations are confined to leather belts. For particulars of the numerous substitutes the various makers have not given any definite information.

Belts work very well up to speeds of 6000 feet per minute, but for such speeds very flexible thin belts are chosen: orange tan or soft raw-hide belts are best for high speeds. By compounding these thin belts, speeds up to 9000 may be satisfactorily used, as the upper belt compels the under one to grip the pulley firmly. If we divide the horse-power foot-pounds by the belt speed we get the pull per horse-power $\frac{33,000}{9000} = 3.55$ lbs.

The following table gives the power transmitted by a 1-inch belt when running on pulleys from 1 to 10 feet diameter.

SINGLE LEATHER BELTING.

1-in.	width of	Single Belt on	Pulley	6 in.	diameter at	6400 ft.	Belt speed	per minute	1 h.p.
1	"	"	"	12	"	3200	"	"	"
1	"	"	"	18	"	2400	"	"	"
1	"	"	"	24	"	1600	"	"	"
1	"	"	"	30	"	1240	"	"	"
1	"	"	"	36	"	1066	"	"	"
1	"	"	"	42	"	950	"	"	"
1	"	"	"	48	"	800	"	"	"
1	"	"	"	60	"	680	"	"	"
1	"	"	"	72	"	533	"	"	"
1	"	"	"	84	"	457	"	"	"
1	"	"	"	96	"	400	"	"	"
1	"	"	"	108	"	355	"	"	"
1	"	"	"	120	"	250	"	"	"

DOUBLE LEATHER BELTING.

1-in.	width	of Belt	on Pulley	18 in.	diameter at	1333 ft.	Belt speed	per minute	1 h.p.
1	"	"	"	24	"	1000	"	"	"
1	"	"	"	30	"	875	"	"	"
1	"	"	"	36	"	730	"	"	"
1	"	"	"	42	"	625	"	"	"
1	"	"	"	48	"	500	"	"	"
1	"	"	"	60	"	400	"	"	"
1	"	"	"	72	"	335	"	"	"
1	"	"	"	84	"	286	"	"	"
1	"	"	"	96	"	250	"	"	"
1	"	"	"	108	"	222	"	"	"
1	"	"	"	120	"	200	"	"	"

A good belt would work up to 30 per cent. more power than given above, but would not be so durable.

The safe pull on a belt depends on its width and thickness.

Good leather has been found to stand a working strain of 300 lbs. per square inch sectional area, and the strain required to actually break it equal to 2700 to 3500 lbs. per square inch.

Safe working tension on leather belts:—

Thickness of Belt.		Strain per inch Section.
$\frac{3}{16}$ inch	=	60 lbs.
$\frac{7}{32}$ "	=	70 "
$\frac{1}{4}$ "	=	80 "
$\frac{5}{16}$ "	=	100 "
$\frac{3}{8}$ "	=	120 "

Belts, Power of

Several rules are given for finding the requisite breadth of belt to transmit a given power, such as:—

1st, Multiply 33,000 by horse-power required, and divide by the length of the circumference covered by the belt on the driven pulley and by half the speed of the belt.

2nd, Multiply 33,000 by horse-power required, and divide by length in inches covered by the belt on driven pulley and by the belt speed in feet.

How these two rules can be reconciled is a mystery, for one would give a belt twice the width of the other, and further they do not take into account thickness of belt.

3rd, Multiply 33,000 by horse-power, and divide by 70 times the belt speed in feet per minute.

These rule-of-thumb methods are perhaps useful in some cases, but misleading in others. A really good well-designed belt drive is a thing very rarely met with in practice; in many cases the belt is overstrained, in many others far too large and understrained. This is a waste of capital in outlay. In other cases the pulleys are too small, and again in other cases the belt too thick or too thin.

In designing a belt drive, not only have we to consider the speeds and power, but also belt contact on pulleys; hence the pulleys are of importance.

Obviously the power transmitted by a belt is equal to the pull P multiplied by speed S and divided by $33{,}000 = \frac{S \times P}{33{,}000} = \text{H.P.}$, so that the higher the belt speed the smaller pull required.

Slipping belts are always found to be running at slow speed on small pulleys. Increasing the size of the pulleys not only increases the area of belt contact, but increases also the belt speed, both tending to drive without slip. It is therefore safe to use the highest belt speed possible in every case. Mr. Tullis invented what he calls compounding belts; that is, to use separate thin belts one on top of the other in cases where the belt speeds and pulleys are such as to make the work or pull too much for one belt. Prior to this discovery of compounding, belts were made double or treble of leather riveted together; but any one who has had an opportunity of testing the power absorbed by these double and treble riveted belts, would never again use them on dynamos. The compounding leaves each thickness of belt free and pliable, and each takes up its share of the pull while their weights and pressures are added on the belt contact on the pulley, and a test made of the power absorbed gave results remarkably low; thus, compounded $\frac{3}{16}$-inch belts absorbed in themselves 60 per cent. less power than that wasted in a $\frac{3}{8}$-inch double rivetted belt.

Compound Belts

A compound drive with three belts is shown in Fig. 1. And in Fig. 2 we have a compound drive from one main pulley to three other pulleys, one over the other.

Compound driving is a simple and most trustworthy means of transmitting power without loss from slip. By adopting compound belts much space is saved that would otherwise be required. The cost of a narrow pulley is, of course, much less than the price of a wide pulley. Two 20-inch belts, working compound, will transmit more power than one 40-inch belt will do, working from a wide pulley. In the case of the narrower belts, the cushion of air between the pulley and the belt is much easier got rid of from pressure than it is possible in the case of the wider belt; while, at the same time, these belts check the influence of centrifugal force upon each other. The outside belt is the more powerful belt of the two, because it travels at a higher speed and covers a larger diameter than the belt next the pulley.

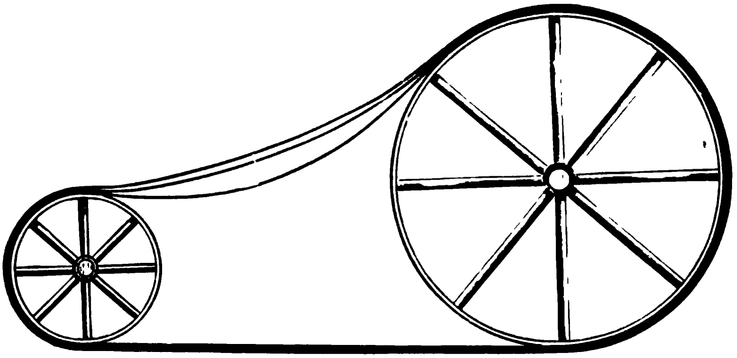


FIG. 1.—Compound Drive

Much good belting is destroyed because it is too thick for the diameter of the pulley. A thick piece of leather being forced to bend round a small diameter becomes destroyed from the compression of the inner fibres. This outer pressure causes the inner side to buckle up and form small wrinkles (like bending the hand inward at the wrist). These wrinkles become cut, through slipping friction, and in a short time the inside of the belt shows open cracks, and the life of the belt is about finished. Often the disease is made worse by using a still thicker belt, whereas a belt of less than half the thickness would do all the work without trouble.

While driving on pulleys of 4 inches diameter and under, the belt ought to be barely $\frac{1}{8}$ inch thick. On pulleys $4\frac{1}{4}$ inches to 8 inches diameter, the belt ought to be about $\frac{5}{32}$ inch thick. On pulleys $8\frac{1}{4}$ inches to 12 inches diameter, the belt should be about $\frac{3}{16}$

inch thick. On pulleys 12¼ inches to 18 inches diameter, the belt ought to be bare ¼ inch thick.

On any diameter above 18 inches, heavy leather can be used to profit.

Of course, if one thin belt cannot transmit the power, two compounded will transmit double the power.

To get perfect belt driving, a very great deal depends on the form of the pulleys. There are many "things" called pulleys that ought to be consigned to the scrap heap, rather than be hung on shafts. Many of these pulleys are bad because the rim is made of much too thin sheet-iron or steel. Many of them have a convexity of ⅛ inch at some places, 1/16 inch at others, flat at others, concave at other places. It is necessary to fill in some of these hollows with thin leather packing and cement to keep the belt on the pulley. There is no proper standard to which pulleys are made. The cause of much loss of power and destruction of belting is due to the high convexity of which most pulleys are made. Pulleys are of all forms—from flat to 1½ inch of convexity. No belt can get down to its work when running on pulleys with a high convexity. A belt will only develop its full strength when it is allowed to take a full grip of its work, by every inch of its width coming in contact with the face of the pulley. You will see important belts every day, in some of our most modern concerns, where not more than the half of the belt is in working contact with the pulley. A 30-inch belt working on a pulley, having a convexity of ⅝ inch to ¾ inch, running at a high speed, will be doing no more work than an 18-inch belt would do on the same pulleys.

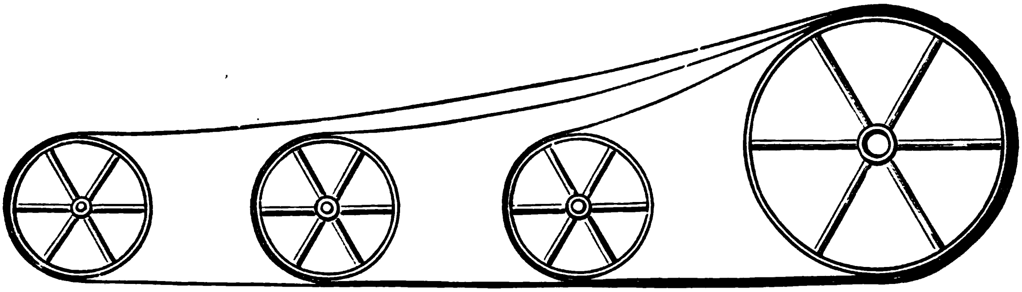


FIG. 2.—Compound Drive, Parallel

Some makes of dynamo are turned out with a balance-wheel much too near the edge of the belt pulley. Trouble often arises from screwing up the dynamo on the bed-plate. One turn more of the screw on one side than the other will cause the belt to seek the longest side—which, as often as not, will be the side nearest the wheel—with the result that slight rubbing soon works a long side on the belt, which, by degrees, becomes useless before the belt-maker is made aware of the fact. One inch of space at least ought to be allowed between the pulley and the balance-wheel.

There are many electric installations driven by gas-engines where a little slip of the belt allows the shock from the explosion to pass off without causing a flicker in the light, or an unsteady motion of the needle on the voltage plates. There are also many steam-engines which get more steam on one side of the piston than on the other, with the result that the shock is passed through the belt, the slack side showing undulating forms like running waves. This thrashing movement of the belt is apt to transmit an unequalised and unsteady load of power to the driven pulley. With the idea of curing this, attendants generally make an attack on the belt, which they go on shortening, pulling it and everything else to pieces, when the reverse ought to be done. In many cases such as this the trouble has been cured by running the belt with the tight side uppermost.

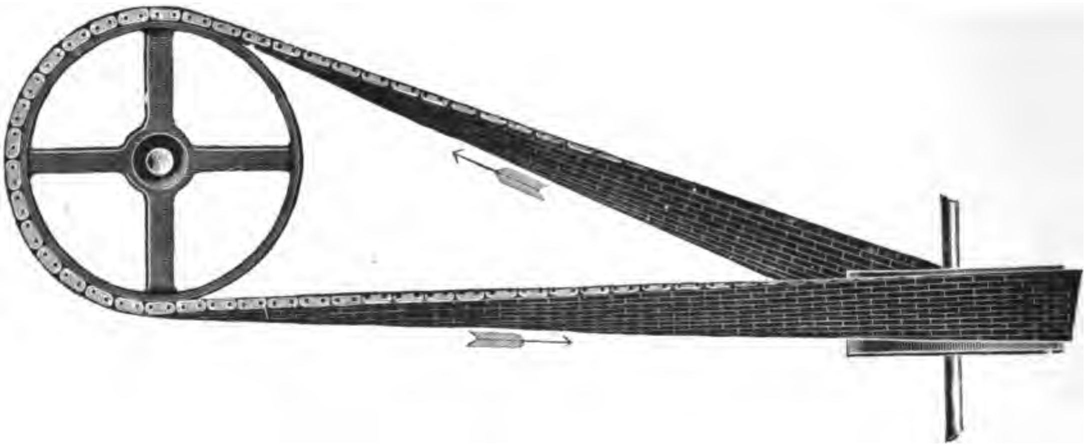


Fig. 3.—Quarter Twist Drive

Shafts at Right Angles.—This class of drive is often the cause of much trouble. A short belt has a poor life; and if the power wanted demands a wide belt, then the strain upon the outside of the twist becomes very great. In using ordinary flat belts for this class of drive, it will be observed that a large portion of the belt assumes a slack appearance on the inside of the twist, which never comes in contact with the face of the pulley. Very often only one-half of the belt is really doing the work. This want is now met by the long-sided belt. By giving the distance between the centres and the diameter of both pulleys, a long-sided belt can be made that will curve to the twist perfectly, bringing every inch of the width of the belt in full contact with the face of the pulleys, without straining the belt more on one side than the other. These belts ought to be made of light-weighing, thin, tough, pliable leather. This class of belt works splendidly whether driving vertical or horizontal shafts. Compounding this class of drive gives perfect results, while at same time such belts do not require to be kept working under high tension.

Heavy belts on this class of drive have to be kept at the work under high tension, because a heavy belt will hang away from the lower vertical pulley, or slip off a horizontal one.

Fig. 3 represents Messrs. Tullis's long-sided quarter-twist belt. Fig. 4 shows the relative positions of the driving and driven pulleys, being a plan and elevation.

It is often necessary to drive from a vertical to a horizontal shaft, and either a quarter-twist belt or a rectangularly bent belt over guide pulleys can be used as shown in Fig. 5, wherein a vertical turbine is belted to a horizontal dynamo shaft on a higher level. Fig. 6 represents a tapered cone drive.

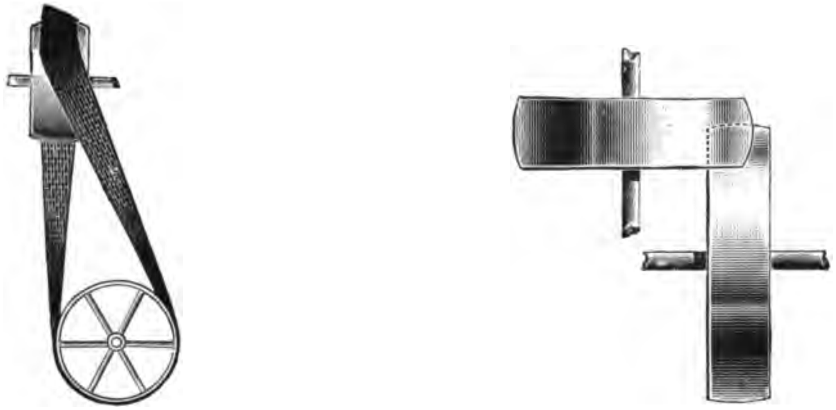


FIG. 4.—Quarter Twist Drive

Tapered Cone Driving.—This is a class of drive which, in the past, has given much trouble. The life of an ordinary flat belt is generally short; the more so if the cones be short and the taper abrupt. The ordinary flat belt keeps continually climbing towards the greater diameter of the cone, and so destroying itself by rubbing against the shifting gear, while, at the same time, often less than the half of the belt comes in contact with the cone. Since the introduction of the thick-sided and tapered link belt for this class of drive, these past troubles are cured by simply making the belt to the form of the cone. These belts are now driving successfully on abrupt tapers, on which ordinary belts could not transmit the power at all. Some of them are working grandly—being ⅝ inch thick on one side, and tapered in 6 inches to 2½ inches thick on the other side. They are made with protection edges, to save the belt from wear when rubbing against the shifting gear. When the power wanted must be transmitted by an open belt, put a full twist on both sides of the belt, as this puts the thick and thin side of the belt in contact with the greater and smaller diameter of the cones; also, when the power has to pass through an ordinary cross-belt drive, the thick and thin sides of the belt will naturally come in contact with the smaller and greater diameter of the cones, thus ensuring a level-bearing surface of the whole of the belt face upon whatever portion of the cones it may be working, and at the same time securing an equalised strain over the entire belt. By making this belt with a convexity on the top side, one or more ordinary flat belts can be run compound on the top of the tapered one.

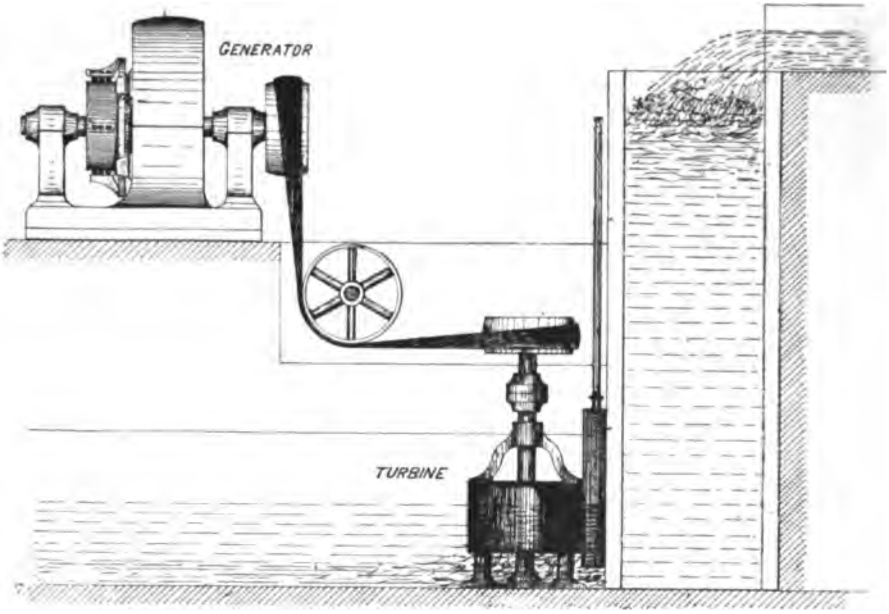


FIG. 5.—Generator driven by Turbine with Shafts at Right Angles

In electric locomotives, whether for road or rail, a continuous variable speed gear is a great desideratum. All the variable speed gears are limited in action and go up or down by jumps by shifting from one gear wheel to another, so that only a few speeds are available and these differing considerably from each other: this kind of "per saltum" variable speed gear is in use on oil motor cars, where it may be tolerable, but it has many drawbacks for larger powers.

The tapered cone and belt drive was the only solution of the problem at present, and was often used on a small scale with the drawbacks already mentioned, which drawbacks are entirely overcome by the thick-sided link belt described above. It however

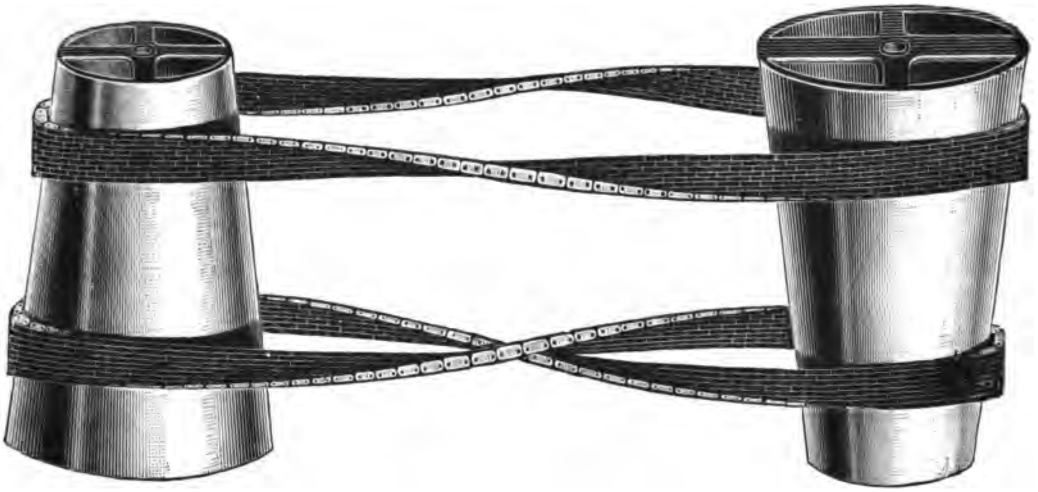


Fig. 6.—Tapered Cone Drive

is cumbrous and takes up too much space for large powers used in traction work. But if run at fairly high speed and on cones tapered 3 to 1, a varying speed of 9 to 1 can thus be obtained. It is remarkable that no wheel or other simple mechanical variable speed mechanism exists capable of transmitting large powers except this belt and cone system.

In the chapter on Electric Traction some auxiliary methods

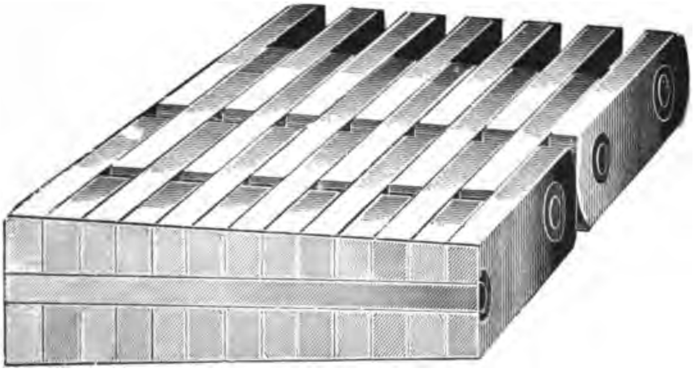


Fig. 7.—Thick-sided Link Belt

shall be described which have been proposed. The electromotor is essentially a constant-speed machine when run by alternating currents, and hence the importance of some variable speed gearing by which speed may be gradually increased or decreased by simply pulling a lever or belt-shifter.

Fig. 7 represents a section of this tapered link belt for cone driving.

Chonata cotton belting is made of specially hard woven, long-staple cotton canvas, bound together by an indissoluble mixture of vegetable gums, which entirely permeate the fibres of the canvas while in a state of high tension. The result is an extra supple homogeneous textile, waterproof belt, which never hardens or becomes rigid when off work, such as is the case with canvas belts cemented together with gutta-percha and balata. The never-changing, yielding nature of this belt gives it a grip of the pulley nearly equal to that of leather, while the stretch is almost nil.

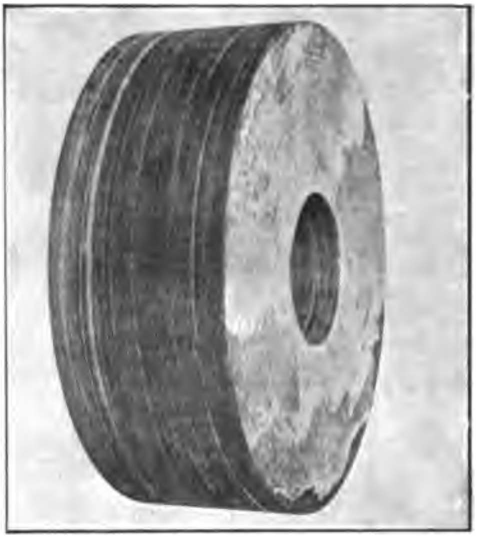


FIG. 8.—Raw-Hide Blank

A well-designed belt drive with a good belt properly selected both as to materials and thickness, is still the most satisfactory connection between an electric motor and its work. Next to the belt comes raw-hide toothed gearing; this gearing requires to be accurately machine cut, the teeth short and fine in pitch.

The Figs. represent the various stages of construction. Fig. 8 is the blank built of raw-hide washers, with thin glue between; the built-up blank is subjected to hydraulic pressure, to squeeze out all superfluous glue, and the pressure is maintained for some considerable time; they are then allowed to dry thoroughly. They are turned up and fitted with a metal bush with three keyways as shown in Figs. 9 and 10, and may have a pair of flanges fitted as shown in Fig. 10.

Raw-hide Spur Gear

The teeth when cut should be almost transparent, looking like tortoise-shell or horn.

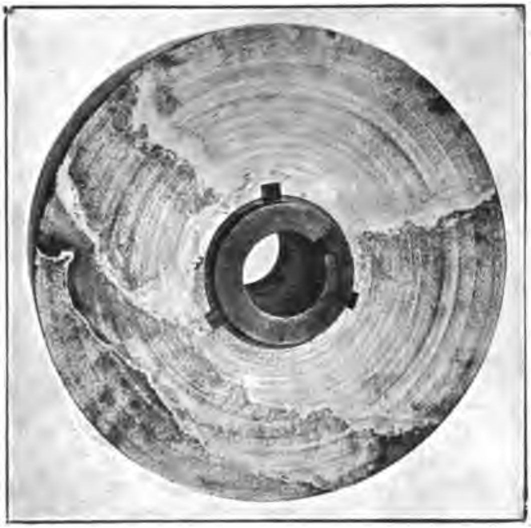


FIG. 9.—Blank Fitted with Metal Bush

Machine-cut helical gear such as is shown in Fig. 30, Vol. III.,

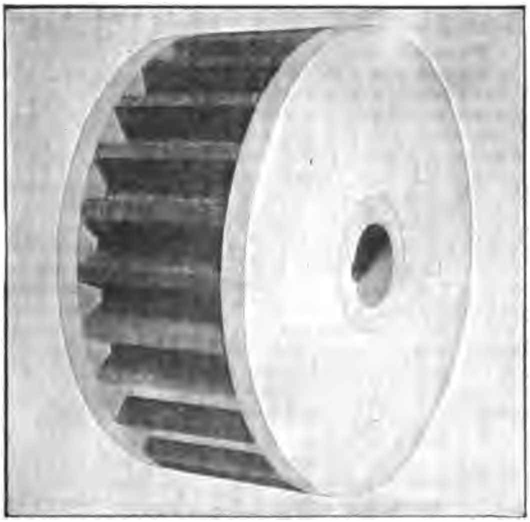


FIG. 10.—Finished Raw-Hide Gear

on the De Laval turbine, is much used for high-speed drives but is expensive. We have already in Vol. III. referred to flexible couplings as used by Westinghouse with and without insulation:

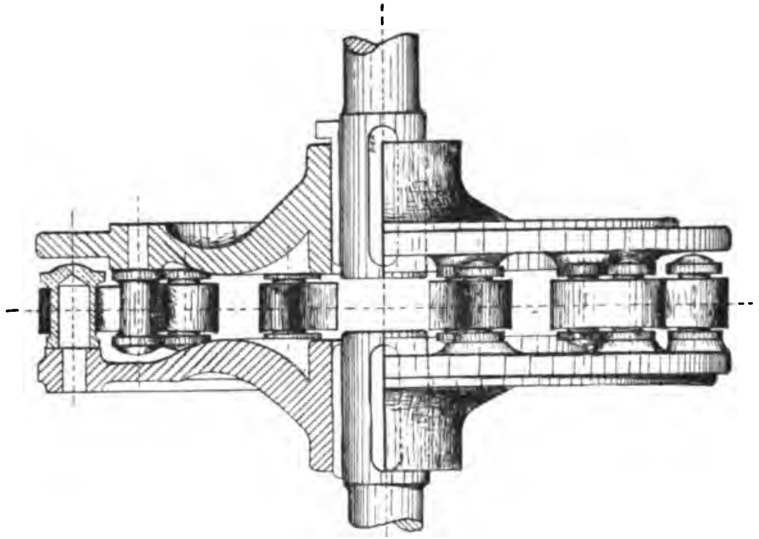


Fig. 12

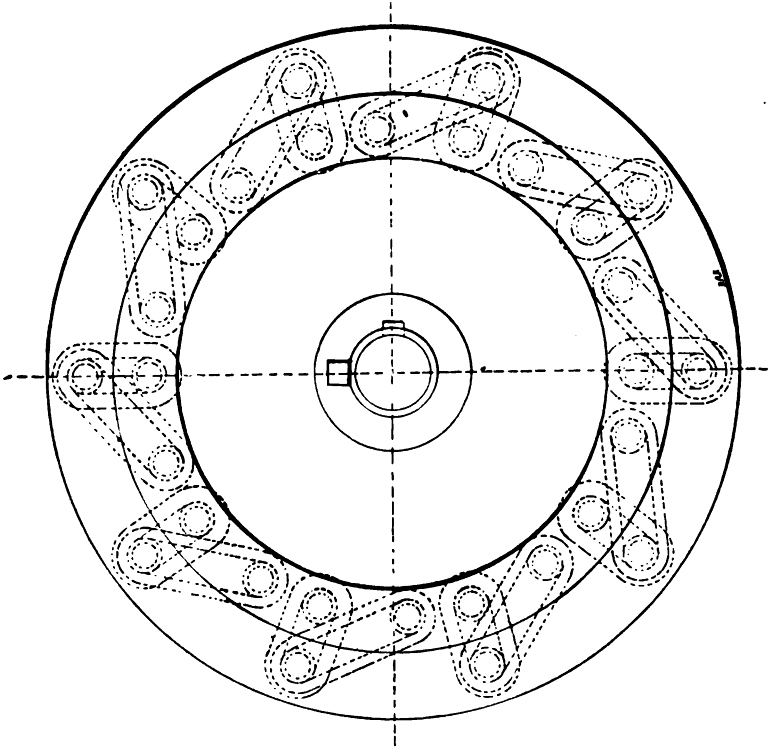


Fig. 11

Raffard Flexible Coupling

another interesting insulated coupling is the Raffard coupling, much used for high speed.

Friction Clutches

In the "Raffard" couplings, Figs. 11 and 12, two discs on the shaft are connected by indiarubber bands, which have a small initial tension when the shafts are not driving. The figure 11 shows the position of the bands when the shafts are at rest and the position they take when driving. The coefficient of elasticity of the rubber may be taken at 120 lbs. per sq. in. The limiting strength when driving should not exceed 50 lbs. per sq. in. It has been used extensively, even for transmitting large amounts of power, and works very satisfactorily. It is most suitable for connecting shafts running at least 250 revolutions per minute.

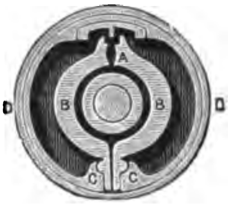


FIG. 13
Friction Clutch

We have also frictional couplings and frictional driving pulleys in use.

One frictional driving pulley used on induction motors acts by centrifugal force, so that it allows the speed to rise to nearly full speed, when it then seizes and drives. The principle of it may be gathered from an illustration of a friction clutch, Fig. 13. The outer rim D runs loose on the shaft, and spring ring C, weights BB, hinged to the spring ring C, fly out when revolved and expand the spring ring until it seizes the pulley and drives. There are various types, but they are same in principle.

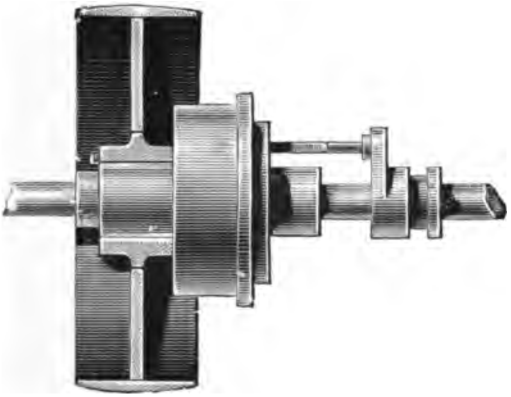


FIG. 14.—Friction Clutch and Pulley

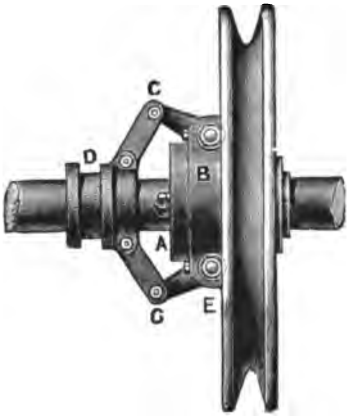


FIG. 15.—Friction Clutch and Pulley

The same kind of clutch is used for shafts and pulleys and operated by levers sliding out or in a wedge at A, as made by Bagshaw & Sons, and shown in Figs. 13 and 14.

Another good type of friction clutch by Mather & Platt is shown in Fig. 15 for a rope pulley. Pushing forward D raises the levers GG, screwing up two half-hoops 8, to grip the hub of the pulley. Much the same class of coupling is shown in Figs. 16 and 17 for large powers.

Fig. 17 is a front view, and Fig. 16 is a transverse section showing friction wheel or internal part of clutch and its relative position with a shell or external part to be driven. A is a shaft, or prime mover, on which is keyed boss B; from the boss B are two arms C, and the rim D, forming the internal part of clutch, consisting of one casting. The rim D is divided transversely at E, but retains unity in consequence of the said rim D being connected with the arms C. The sockets G, G1 are cast in the rim D. In sockets G1 are placed adjustable round nuts H, formed at each end with flanges I, having "tommy" holes J. The nuts H are carried in square blocks K formed in halves, with a slight clearance between. In nuts H and K are inserted the ends of left and right hand screws F. By means of levers L, L1, which are connected to the screws F and to the sliding sleeve M, the ends of the screws F cause the rim D to expand or contract when the sliding sleeve M is moved nearer to or further from the face of the clutch. By these operations the rim D expands when power is required, and binds upon the internal surface of external shell F, and this causes the said part F to rotate at equal speed.

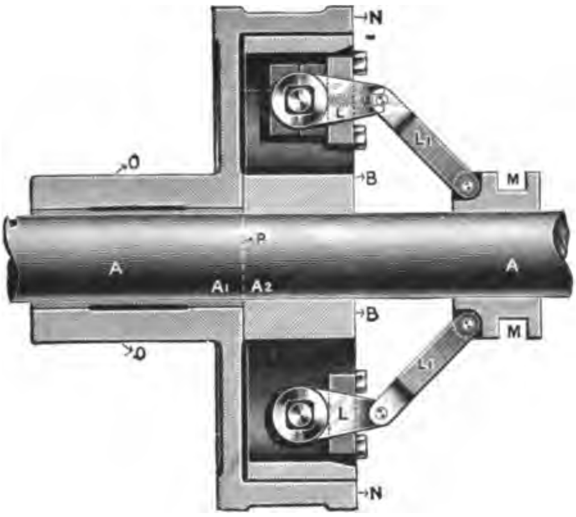


Fig. 16

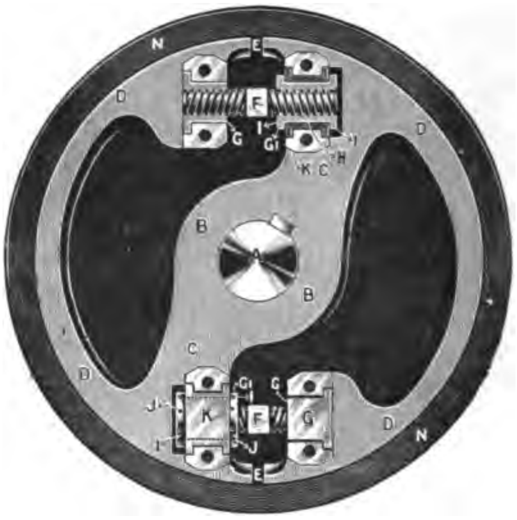


Fig. 17

Friction Clutch

We now come to the purely magnetic coupling as shown in Fig. 18, a design by Mr. Sayers. Here a coil is carried in a recess in the pulley, and is connected to an electric circuit by slip rings CC, and brushes BB. The pulley is loose on the shaft and faces a plate of iron A, keyed to the shaft. Upon energising the coil the pulley is gripped to the plate A, and is driven. The power can be applied gradually by a graduated resistance switch or by a liquid switch.

Another type of magnetic coupling is shown in Figs. 19 and 20. As designed by the author on the dynamic principle it consists of an internal field magnet AA, consisting of two iron checks enclosing an energising coil C, connected to two slip rings and brushes BB. The armature has internal slots, each with a short circuited coil of copper, carried on a spider F, on the shaft which is running; the magnet is carried on the shaft to be driven. Upon energising the magnet by current, currents are induced in the armature coils, and these acting as motors the magnet is pulled round to follow the armature with a torque depending on the strength of the magnet. There is no friction, and any speed may be maintained for any length of time, from a mere observable move to 95 per cent. of the full speed of the driver. By a tapering of the faces it can be made so that at full speed they grip fast. It is not only a coupling but also a variable speed gear, and is now under trials for traction purposes with constant speed alternating motors.

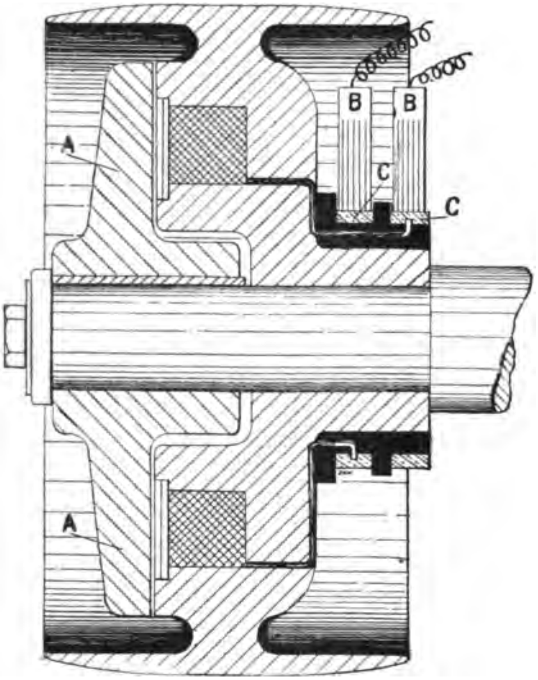


Fig. 18.—Magnetic Clutch

Dynamo Clutches

In order to use fairly high-speed motors, for most purposes a counter shaft on the motor itself is very useful. There is no advantages whatever in slow-speed motors, while the cost is inversely as the speed. If, therefore, the addition of a counter shaft is not more costly than a reduction in speed of the motor by itself, it is to be recommended. Some electrical engineers making motors with counter shafts attached, place a very high value on the counter shaft, so that there is little advantage in having it at all, and the extra money would be better spent on a larger motor at slower speed; but as a rule it is found a saving in first cost to have the high-speed motor with self-contained shaft. Such a motor, by Greenwood and Butley, is shown in Fig. 21. The small gear wheel is of raw hide, the large one cast iron, both accurately cut to run noiseless.

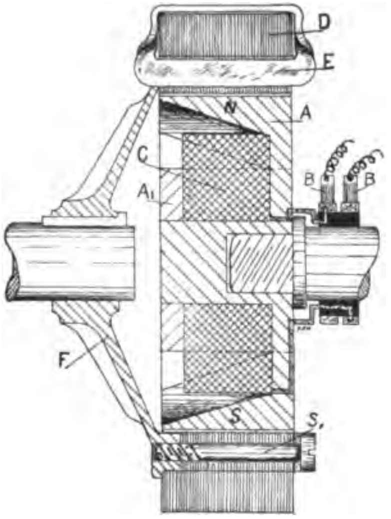


Fig. 19

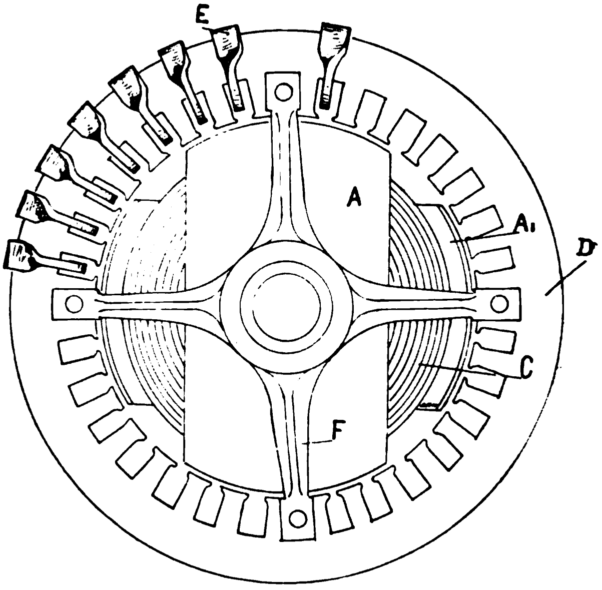


Fig. 20

Dynamo Magnetic Clutch

Another useful gear ready made for crane, hoist, and other purposes, where a very slow speed is required, is the worm and wheel gearing, one example of which is shown in Figs. 22, 23, ready for direct coupling to a motor; the wheel is of phosphor bronze, with a solid steel worm on the shaft, the bearings are fitted with anti-friction metal, and the worm may be on the upper or lower shaft as desired, but it is better in the lower position working in an oil bath. The example shown is by Bodley Bros. & Co., Exeter.

In order to illustrate the principle of electric motor power transmission as it ought in every possible case to be carried out—that is, to have the motor right up to the work to be done, without any

Reduction Gears

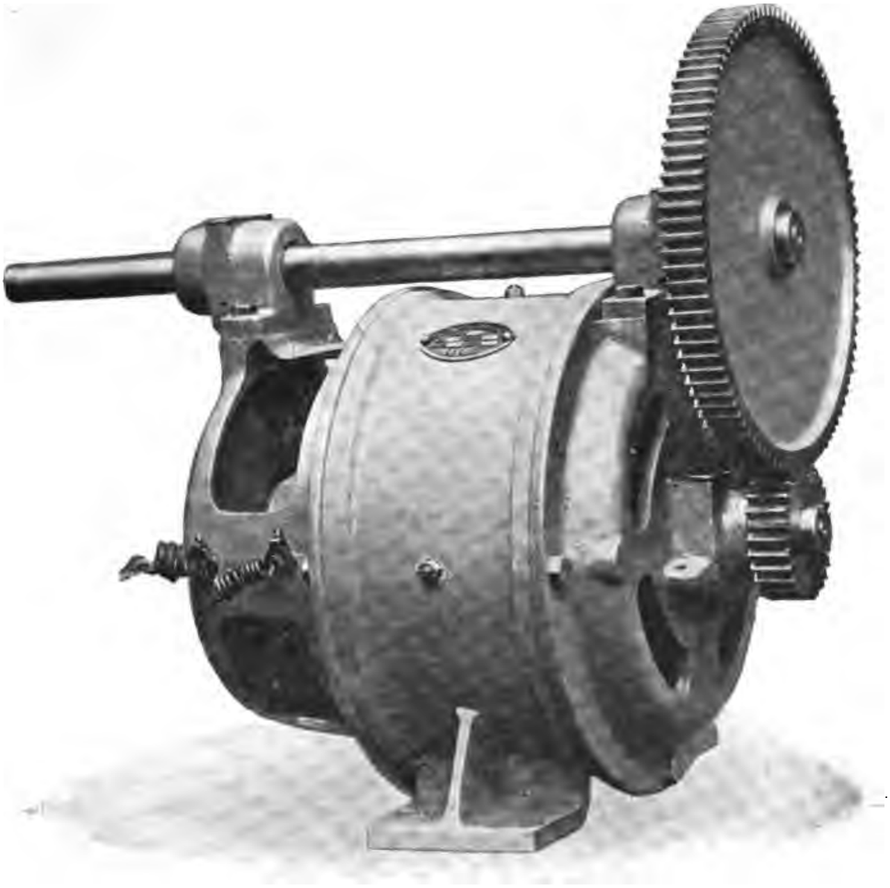


FIG. 21.—Motor fitted with Reducing Gear

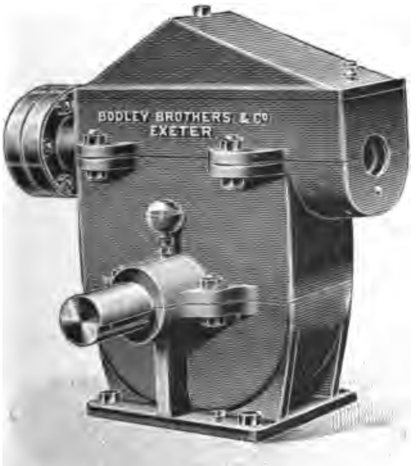


FIG. 22
Reducing Gear with Worm on Top

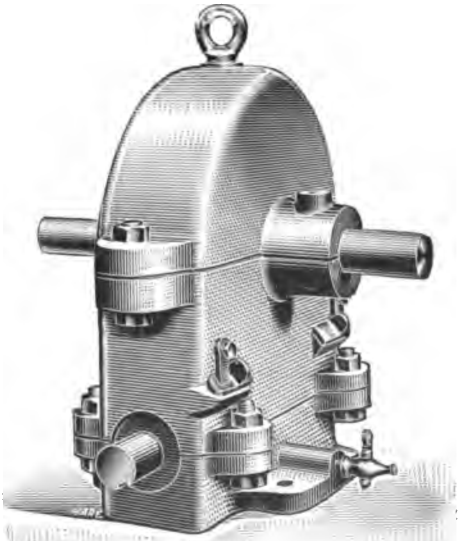


FIG. 23
Reducing Gear with Worm at Bottom

intermediate gearing—Fig. 24 shows a motor fixed on the slide-rest of a lathe, and carrying an emery wheel B for grinding up a

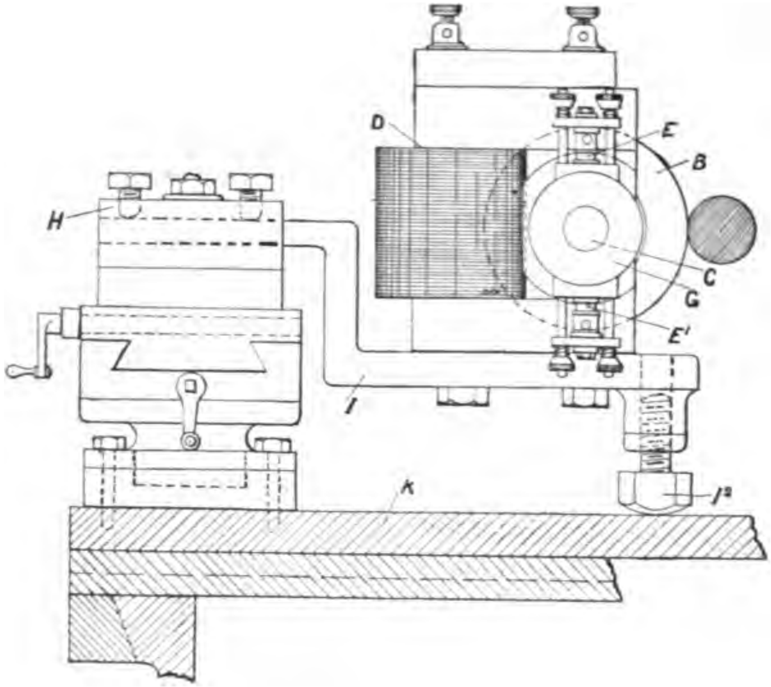


Fig. 24.—Motor fixed on Slide-Rest of Lathe for Grinding Shafts

neck on a shaft. Motors applied to machinery should, as in this case, be as direct as possible.

This arrangement is one designed by Messrs. Chamberlain and Hookham.

CHAPTER II

COMPLETE INSTALLATIONS

By a complete installation is meant a whole system for supply of electrical energy from the coal pile to the switches for light and power.

And exactly what that system should be is the first question.

The most common installation is one for lighting only. And strange as it may seem, it is a fact that the majority of municipal installations come under this heading. A very eminent consulting engineer, responsible for many of these plants, informed the author some years ago, when advocating a system for both power and light, that the supply of power was not worth considering; therefore the system best suited for the double supply was of not much use.

The next most common installation is one for supply of both light and power. Most people with ordinary common sense would conclude that, other things being equal, such a system should be universally put up; for although power may not just at present be wanted, it may possibly be required in the future.

It may be contended that any system of supply can give power and light; perhaps so, but all systems cannot do so with equal economy, convenience, effect, and safety.

We have three systems of supply distinguished by the current:—

C.C.	Continuous current.
S.P.C.	Single phase alternating current.
P.C.	Polyphase current.

S.P.C. current need not be considered very fully; it is to most consumers worthless, and its supply should be restricted if on no other ground than that it is deadly dangerous at all pressures over 100 volts. This is a simple undeniable fact; deaths have occurred often by simple contact on municipal 200-volt circuits. For the same reason P.C. currents ought also to be limited in use; and all the more so when we know that a C.C. supply can do all that the S.P.C. and P.C. supplies can do, and a great deal more, and do it better too.

The S.P.C. and P.C. supplies are out of place on a consumer's premises. These currents are supremely fitted for the work of transmitting electrical energy in bulk to long distances, to be converted into C.C. for supply; that is their legitimate business. For any other purpose they have nothing to recommend them in any way whatever; and as for supply purposes for public consumption are far inferior to C.C. Apart from danger to life S.P.C. motors are far inferior to C.C. motors in efficiency, and cannot be regulated in speed; same with P.C. motors. C.C. arc lights are better, and incandescent lamps last longer on C.C. circuits. S.P.C. and P.C. currents are of no use for accumulators nor for electrolytic work. Not a single objection raised against these currents can be urged against continuous currents. The vain struggles of those towns saddled with the S.P.C. system of supply, in their endeavours to work it successfully, have failed.

When public bodies come to adopt electric tramways the "Committee" find that after all they must use C.C., and this has led in more than one town to a "change over" entirely to C.C. This "change over" practice has been quite a feature in municipal electrical engineering. They have been "changing over" in pressures, frequencies, mains, generators, lamps, and systems all over the country, with a frequency which reflects a curious light upon the foresight of the technical advisers in the first instance. On the whole those towns at present labouring under the disabilities of a S.P.C supply would be well advised to make a wholesale "change over" to C.C. all at one common pressure of 250 volts.

We may now say that for all supply purposes the C.C. system is by far the best: having decided upon this, there remain several other fundamental questions to settle.

The site is of importance, although it is often chosen without reference to the engineers; but for public supplies the site of a station should be either on a canal bank or on a railway siding, for the easy delivery and discharge of materials. In some towns sites have been chosen in very unsuitable places in this respect. If steam is to be used, the steam generators must be on the same site as the engines and dynamos; but if gas is to be the working fluid, then the gas generators may be at some distance, and that is in some cases of considerable advantage.

The question now to be decided, even before a site is chosen, is whether to use gas or steam engines, a question which must be decided upon the special circumstances of each case; although it is very evident that some of the engineers responsible for existing stations seem to have had stereotyped plans, as the same plant is to be found in dozens of cases, under totally different circumstances. It is of course much less trouble and work to put down plants, repetitions of others, especially when public funds can be drawn upon to make up for any deficiencies; but it is not good engineering. The sound engineer considers each particular installation on its own aspects, also looks into recent improvements with a view to utilise them. He does not display weakness by refusing the tenders of those who have not "done similar work before." We will suppose the questions have been carefully considered by a skilful engineer with a perfectly open mind and unbiased in any way, and not influenced by the committee or any member thereof; and steam is decided upon, probably because water can be had plentifully for condensing, and coal is cheap in the locality.

The steam plant may now be considered in more detail, and the boiler selected. These are of two types—the water-tube boiler and the shell boiler. Station engineers have long held that the water-tube boiler had peculiar adaptations for electrical works, principally because it is more compact, occupies less floor space, and is a quick steam raiser. Especially was this the case in the 110-volt period in electrical engineering, when stations were crowded into the back alleys of a densely populated area so that the mains would be short.

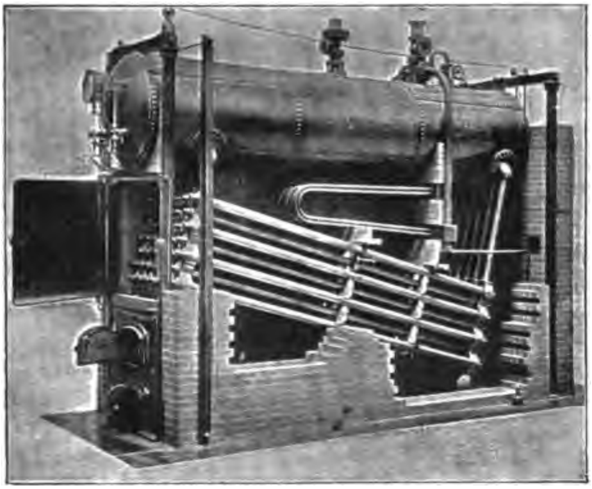


FIG. 25.—Water-Tube Boiler with Superheater

We need not enter fully into boiler construction, but showing the nature of the water-tube boiler by the sectional view of the Boblock and Willcox boiler in Fig. 25. It is perhaps the most commonly used water-tube boiler in electricity works; and its design has been very carefully developed in every way to meet the requirements of a boiler for the purpose. The superheater is shown in the ⊂ tubes, above the sloping water-tubes. Fig. 25 shows the furnaces also.

But wherever possible now, stations are put down where the engineer is allowed room enough for his works, and so we find the shell boiler of Lancashire type also in favour. It is simple, safe, reliable, easily kept in order and inspected, can be worked up to 200-lb. pressures, but generally about 180 for triple expansion engines. The mechanical stoker is generally applied as shown in Fig. 26.

The flues should be corrugated; they can then be made of thinner metal, and they expose a larger heating surface.

The whole of the heat is not generally given up to the boiler by the flue gases, hence an economiser is used, through which these gases pass on their way to the chimney. The boiler feed-water is pumped through the economiser, so that it takes up some of the heat and enables a hot supply to be sent into the boiler. It consists of vertical tubes, over which scrapers are worked to keep them clear of soot and tar; practically, it is an extension of the boiler heating surface, capable of withstanding considerable fluctuations in tem-

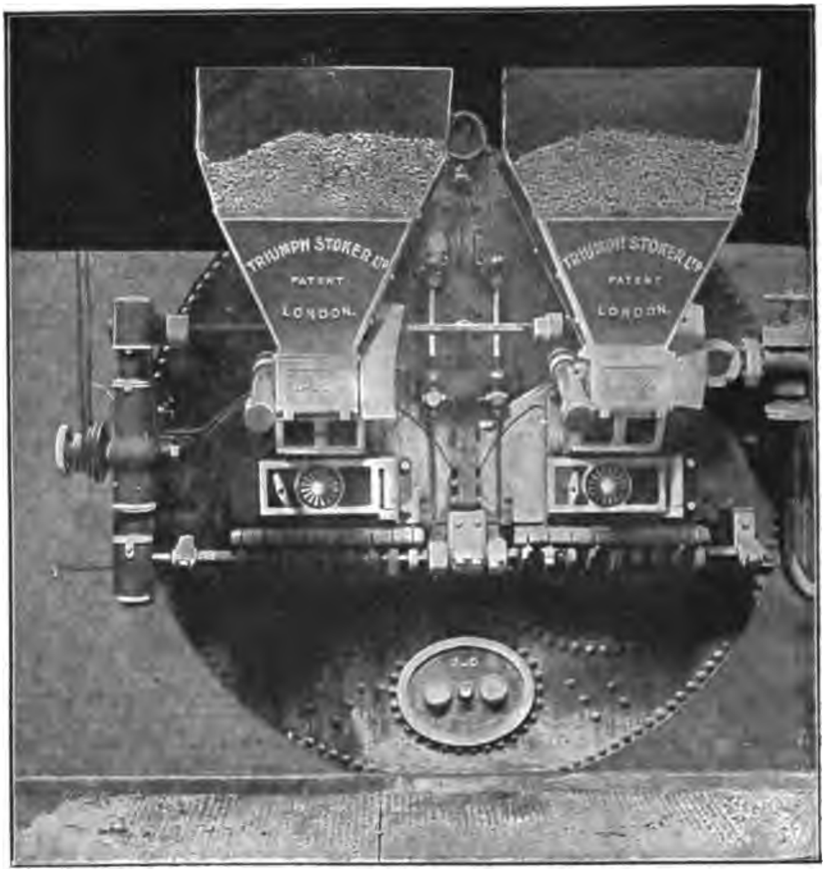
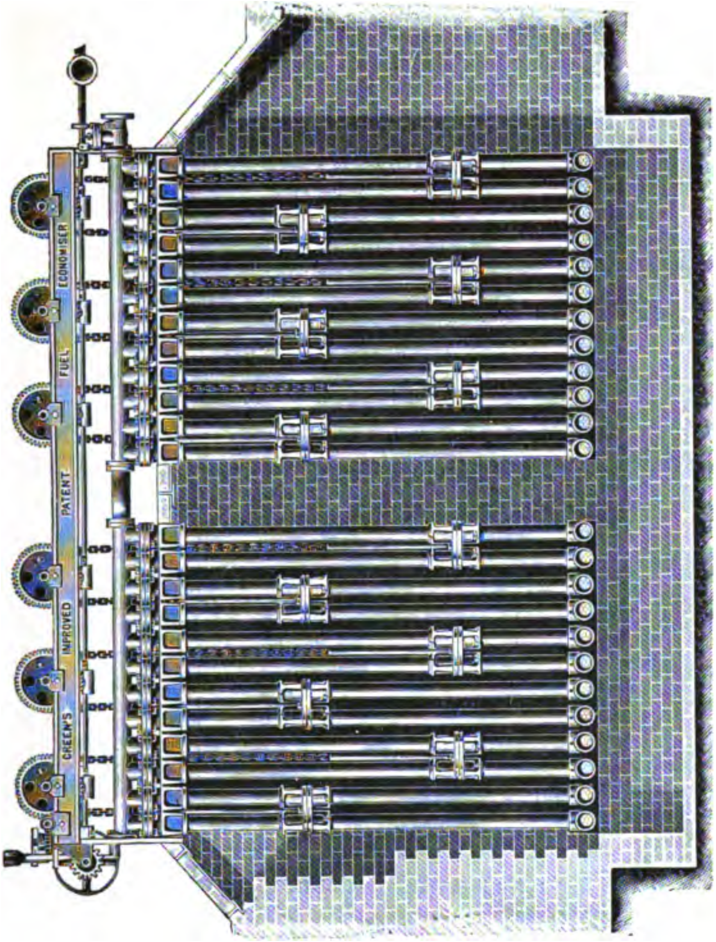


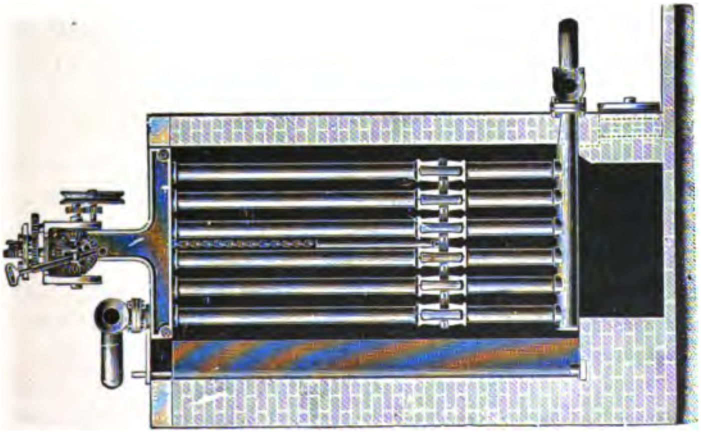
FIG. 26.—Mechanical Stoker

Green's Economiser



Elevation

Fig. 27.—Fuel Economiser



End View

perature. Fig. 27 shows Green's economiser. Each tube will heat about 70 lbs. of water per hour, and we may calculate upon one tube for every 3 i.h.p. The chimney is a subject of considerable interest. In most cases it is depended upon entirely to provide the furnace draught.

The following table shows the capacity of chimneys at various heights :—

Actual Diam. in Feet.	Effective Area in Sq. Feet.	Height of Chimney in Feet.			
		60	80	100	125
		Coal burned per Hour in Lbs.			
1.0	·35	46	...	...	...
1.5	1.07	141	...	...	...
2.0	2.18	287	331	...	...
2.5	3.69	485	561	...	...
3.0	5.59	735	850	950	...
3.5	7.85	1040	1190	1340	...
4.0	10.5	1390	1600	1790	2,000
4.5	13.6	1800	2070	2320	2,580
5.0	17.1	2250	2600	2810	3,250
5.5	20.9	2760	3180	3550	3,960
6.0	25.2	3320	3830	4290	4,790
7.0	35.0	4610	5320	5940	6,640
8.0	46.0	6080	6990	7810	8,730
9.0	48.5	7700	8900	9950	11,100

In some cases fans are employed, and in others steam jets, to force the draught.

In many places a rule is made that no chimney shall be less than 90 feet in height above the pavement. Other rules are—Base of chimney, if square, must be one-tenth of the height; if octagonal, must be one-eleventh; if round, must be one-twelfth; tapering 2½ inches in 10 feet; brickwork, 8½ at top, increasing by 4½ inches every 20 feet down.

Where steam requires to be maintained at a constant pressure for long periods of time, mechanical stokers are of much value, as the fuel is regularly fed in in small quantities, well spread. They save labour and prevent smoke, the fuel being thinly spread. They are of various types. One type acts much like a shovel in scattering the fuel at intervals over the fire. Another type carries the fuel on a link grating gradually forward from the furnace mouth to an ash-pit at the far end. The speed of the grating and the quantity of fuel are so regulated as to ensure the complete combustion of the fuel before the ash is tipped into the ash-pit.

In the sprinkler type the bars of the fire-grate are moved up and down continually to keep them from clinker and choking up with ashes. In some the motion of the fire bars is backward and forward.

The following are the general results claimed for mechanical stoking :—

1. A regular, even, and complete combustion. The coal, in fixed quantities, is thrown or sprinkled automatically over the fire at intervals of a few seconds, and in such a way that two successive charges never fall in the same place. The result is a clear, bright fire of a uniform thickness, not exceeding more than a few inches in every part, thus ensuring a most perfect combustion. This is proved by the small quantity of ashes and clinkers to be removed.

2. The furnace doors never require opening for stirring the fire or clinkering (both these processes being entirely eliminated and done away with), thus preventing the inrush of cold air, with consequent lowering of heat, and sudden stresses on the boiler caused by fluctuating temperatures.

This result is obtained by the alternating backward and forward motion of the bars, worked by chilled cast-iron cams slipped on to a square steel shaft, which rotates very slowly by means of its worm gearing.

In an apparatus of this kind (Fig. 26) the moving parts should be removed as far as possible from the high temperature of the flues. The principal shaft X is placed for this reason high above the flues; its bearings are protected from coal-dust and are easily lubricated.

None of the parts of this stoker project into the combustion chamber. A series of five steam-jets are blown in below the fire bars in order to keep them cool and clean, and to increase the draught, but it is a doubtful practice as to economy, for a good deal of steam may thus be wasted.

Where the load varies from hour to hour, the stokers may still be used by driving at a different speed.

In order to get high economy in steam-engines, condensing is necessary, especially with steam turbines; it is therefore of considerable importance to secure a plentiful supply of cold water, naturally, if possible, from a canal or river; if a natural source is not available, there are two artificial methods of supply—first, to provide a reservoir of water sufficiently large in area to keep cool while returning the condensing water to the reservoir continuously; this requires a considerable area of surface from 2 to 2.5 square yards per i.h.p.

In towns and cities this area is not as a rule available at cheap rates. The other method is to use water-coolers with a small reservoir. These are of many various types.

In the simplest form the hot water is thrown up into the air in the shape of a fine jet of spray. It is a well-known physical fact that cooling of liquids is most rapidly effected by evaporation, the vapour carrying off more heat than that required merely to raise its temperature, and evaporation is dependent on the surface exposed to the air, so that by breaking the hot water into a spray, it is thoroughly exposed to evaporation, and rapidly cooled. In all such systems the water lost by evaporation has to be made up from some source.

Where condensers are above the level of the reservoir, the head of hot water is often sufficient for the force to raise the jets; but where the reservoir is not below a sufficient level, a centrifugal pump can be used for the purpose.

One other method is to pump up the hot water to a height, and then allow it to trickle in thin films and drops through a cooling-tower over tiles or broken-brick scrubbers, air being blown up or drawn up continually by a fan; this entails the use of some power to work the pump and fan, and is a method only to be adopted for large powers.

For powers under 500 horse-power, artificial cooling is not to be recommended. There are other auxiliaries to the steam plant such as steam driers to intercept water carried by the steam. These appliances are by no means economical: they may trap the water, but they also lower the pressure, for every device placed between the boiler and the engine increases radiation, condensation, and friction, except that one apparatus known as a superheater. The superheater is a most valuable addition to a boiler. There is no need for steam driers if a superheater is used. And the steam performs more work in the engine when superheated. Superheating has its limits, but a moderate degree of superheat should be provided for in every steam plant.

The superheater is much the same as a dry economiser, consisting of a bunch of pipes placed in the flues so that the hot gas raises their temperature above that of the boiler, and so heating the steam above its saturation temperature, and evaporating any water carried over by the steam.

One can be placed behind the flues of any Lancashire boiler right in the path of the hot flue gases, and just before they pass on to the economiser.

The superheating of steam is worthy of much more attention than it has hitherto received both from manufacturers and electrical engineers. In fact it pays to use an entirely separate superheater with its own independent furnace and coal consumption.

1. Where the arrangement of the setting of the boilers and the steam pipes is such as not to admit of constructing superheaters to form part of the boiler proper without stopping the works, or costly alterations in the steam pipes.

2. For testing engines, &c.

The separately fired type of superheater is composed of a series of boxes or manifolds connected together by U-shaped tubes. The steam from the steam main enters the first box and is conveyed through the tubes into the second, third, and fourth boxes, and so on, passing from the last box back into the steam main.

The gases generated on the grate rise upward, passing through a perforated wall (which muffles the flames and ensures comparative evenness of temperature) into the superheater chamber, and thence through a similar perforated wall into the chimney. The amount of heat passing through the superheater chamber can be regulated at will. The temperature is kept comparatively low, the grate surface required being small.

Any fuel can be burned. The superheater is provided with a by-pass in case of any necessity for repairs, and also with the necessary valves to enable the superheater to be shut off from the steam main if desired without interfering with the general running of the plant. The quantity of fuel required is exceedingly small.

Where superheating pipes are placed in flues a difficulty arises from inconstant temperatures, an uncertainty as regards the actual amount of superheat imparted from time to time. Proposals to overcome this have been made to put the superheater in a liquid bath maintained at a uniform temperature.

So far we have referred to the steam generating and condensing plant only, and there are many details left to be found fully treated elsewhere. We now arrive at the question as to what is the best engine to use? And as we are only considering a continuous-current plant we may leave out of account some classes of engines.

Taking everything into account the steam-turbine stands by far and away the best steam-motor now before the world, and it is getting still better every year. We need not describe the turbines again, but refer to Vol. III. for their description. There is no objection to any high speed either in dynamos or turbines, and if in any case there should be any necessity for a slow-speed dynamo a simple gear driving presents no difficulties.

To show exactly how far the turbine has progressed, the following statements by Mr. Parsons, the pioneer of this engine, will put the matter clear up to date:—

Parsons stated that the use of the compound turbine was commenced in this country in 1884 for driving dynamos; by 1890 about 360 such plants had been set to work in sizes from 4 horse-power to 120 horse-power, the total aggregate at that date being 5000 horse-power; by 1896, 600 turbo plants had been sold, the total aggregate at that date being 40,000 horse-power, and the largest individual plant was of 600 horse-power. At the present time 800 turbo plants had been sold, aggregating 200,000 horse-power, the largest being of 3000 horse-power. On the Continent, Messrs. Brown, Boveri, & Co., of Baden, Switzerland, took up the manufacture of compound turbines in 1900, and had sold 20 plants with an aggregate of 29,000 horse-power, the largest being of 5000 horse-power. The British Westinghouse Company had lately contracted with the Metropolitan and District Railway Companies for the supply of ten turbo-alternators of 5000 horse-power, and several plants of moderate size had also been built by the Westinghouse Machine Company, of Pittsburg. The total aggregate of turbines at work and on order of the compound parallel flow type, for generating electricity in England, and on the Continent and elsewhere, was not far short of 300,000 horse-power. Of economic results, the lowest steam consumption so far recorded had been 17.3 lbs. per kilowatt-hour, with a 1000-kilowatt continuous-current plant, one of several built for the Newcastle and District Electric Lighting Company; this figure corresponded to about 10.2 lbs. of steam per indicated horse-power hour. There is no doubt that still lower steam consumptions per horse-power would be reached in turbines of large size working with superheated steam and a good vacuum. Several turbine plants have been tested after being at work for a considerable time, in order to ascertain if any increase of steam consumption occurred with age, and in all cases no observable increase could be detected. Even greater success has followed the introduction of steam turbines for propelling steamships.

At present there are only the two turbines to choose from—the Parsons turbine working partly by pressure and partly by momentum of the steam, and the De Laval turbine working altogether by momentum.

It has been said that the adoption of a turbine entails the use of special dynamos; that, however, cannot be a serious objection. Dynamo makers must make turbines also, and the most intelligent and up-to-date makers are doing so; the two machines should be built in one shop. As a matter of fact the dynamos now produced have all been designed to meet the special engine requirements.

The fly-wheel dynamo, that absurd creation of the municipal engineers, a mighty machine labouring to produce an insignificant result, a mountain labouring to produce a mouse, was designed particularly to fit large slow-speed engines. The dynamos working between 250 and 500 speed were designed in the first instance for direct coupling to Willan's engines; the designer has a free hand only with gear-driven machines. The peripheral speed of a dynamo should be about 6000 feet per minute maximum whatever its output.

And the bearings and commutator can be run as high as the frictional limits will allow. Small machines at high speeds for electric generators are of course much cheaper in first cost and in upkeep, and he is a poor designer and a worse constructor who cannot make them in every way quite as satisfactory, if not better, than slow-speed machines of larger size.

The turbine creates no noise or vibrations: many reciprocating engines have had to be thrown out and turbines substituted on this account alone; they therefore require no foundations. There is no danger of a cylinder cover being knocked off by water, and they do not require so much of the attention of greasers and fitters, attending to and taking up wear and tear.

Plate 1 represents a station with Parsons turbines, and Plate 2 one with a De Laval turbine set, as typical installations.

Recently a purely pressure turbine has been under trials, and promises to be simpler and more economical at lower speeds than the partial pressure machines.

The dynamos for direct coupling to turbines are of interest for the very highest speeds, those of the De Laval to 20,000 revolutions per minute can be used. The makers prefer to gear down the speeds from that to 2000 or 1500.

But for large current outputs a unipolar direct coupled machine might be used, keeping the peripheral speed of the wheel the same; the revolutions might be, say, 10,000. A unipolar armature may be driven up to 10,000 peripheral speed, hence would be about four inches diameter.

The volts generated per conductor would be $E = Z, N, Nt$, as before, and Z would be limited by the sectional area of the armature in a plane at right angles to its axis. With good Lowmoor iron or soft steel the flow could be as high as 20 per square inch, and taking the area of the section as 12 inches, we would get $20 \times 12 = 240$ English lines, this in one direction, so that we double this as this flow also goes in the opposite direction. $Z = 480$, $N = 10{,}000$, $Nt = 1$, hence $E = 4{,}800{,}000$ or 4.8 volts per bar on the armature. This voltage would do very well for most chemical work and for copper refining. If the one bar consisted of a copper tube as shown in the unipolar machines in Vol. I., $\frac{1}{8}$ inch thick only, it would easily carry 4000 amperes and give a terminal voltage of 4.5 volts, total output of 18 kilowatts; by making the machine with bars, as described in Vol. III., pages 106 and 108, higher voltages can be had. For alternating currents, the machine *par excellence* for the turbine speed is the inductor type of machine, and that form described in Vol. III., pages 205 to 208, would be still better.

If for any reason such as low-pressure steam, no condensing water, or other reasons, turbines cannot be adopted, then, of course, the engineer must adopt reciprocating steam-engine plants. These are very numerous now, and no one seems to be much better or worse than another. The choice is generally a matter of cost, and as they have been noticed in Vol. III., and have been weekly described and illustrated in the technical journals for ten years or so, we need not consider them further here. The preference here seems to be for the moderate speed about 250 to 350 direct-coupled plant.

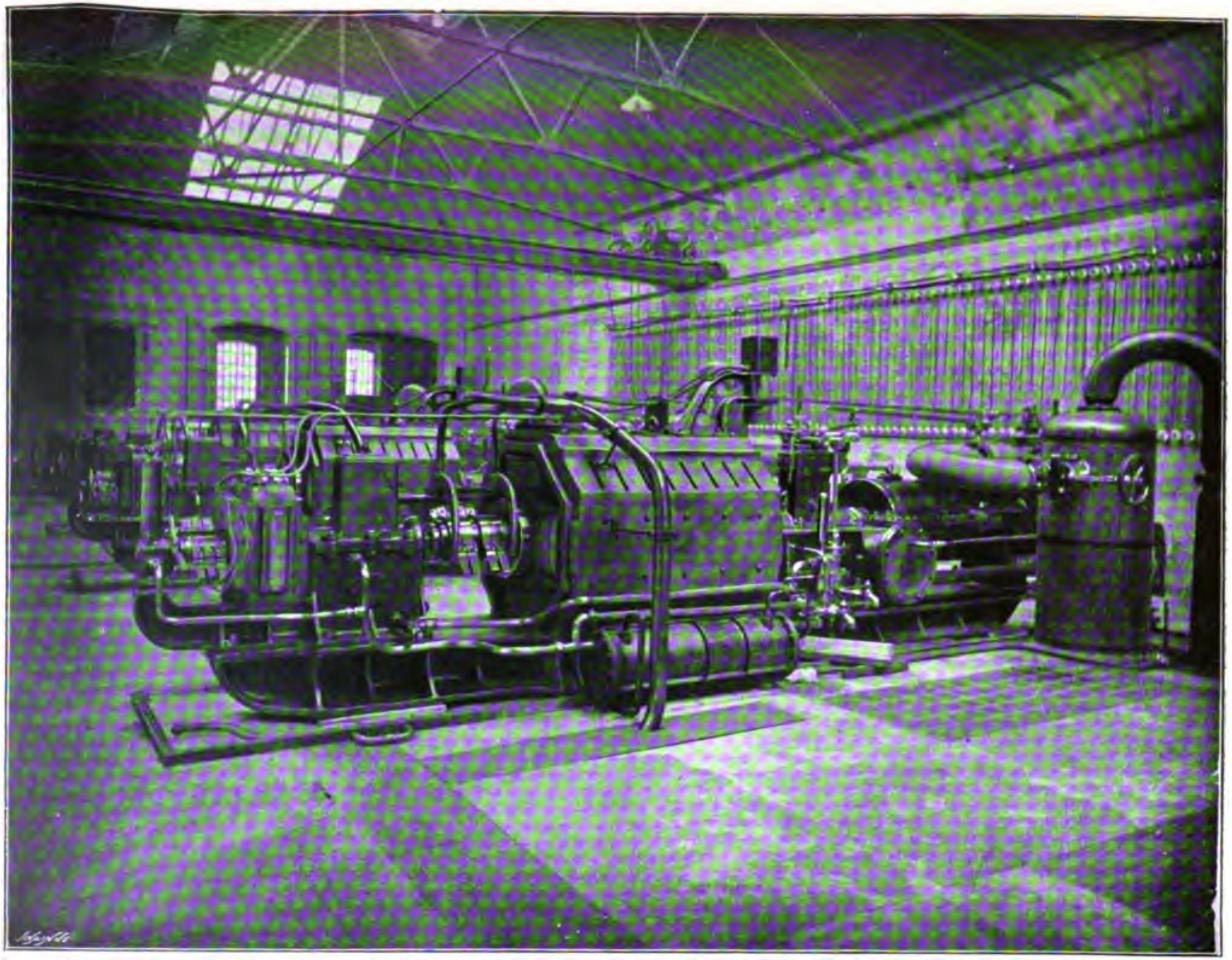
So far it will be seen from the foregoing discussion that the vital questions in the matter of selecting a generating plant are entirely questions of steam and mechanical engineering. The rest of the system beyond the terminals of the generators is electrical work, and has been treated in Vol. II. under switches, switch-boards, cables, wires, and so on.

Steam, with the aid of the turbine, will, no doubt, hold a place above all other fluids for pressure engines for a long time; but gas and oil have come forward with remarkable quick strides, and now offer a power of a very different character from steam.

Both the gas and steam engineer very early in the electrical engineering movement discovered that the continuous driving of an electrical dynamo at constant speed under all loads and conditions was no simple problem. The steam-engine first received the necessary improvements to fit it for the work as it was more easily controlled, and better understood than the gas-engine.

Thousands of little gas-engines up to 50 horse-power or so have been very useful motors to manufacturers of this country, but the engine-makers did not give the question of electrical driving by larger engines any attention. This problem, namely, the design and construction of large engines suitable for direct coupling to dynamos, was tackled and solved, as most of the recent important problems have been, by American and continental firms. It is not that British engineers lack skill, knowledge, and ability, but reluctance to move in the direction of anything new or speculative, content with things as they are. There is also some truth in the statement that, as an investment in this country, engineering manufacturing business is hopeless, in the face of legislative and other outside interferences. However these things may be, the fact remains that the gas-engine, which in the nature of things is theoretically a far superior engine for the conversion of the energy of fuel into electrical energy than a steam-engine, for the simple reason that the fuel is consumed in the engine itself, where its liberated energy should be most effective, yet the efficiency has not yet come up to what might have been expected, a lot of the heat is lost in the cylinder jacket of water, in the piston, and is rejected in the exhaust.

A short discussion of the troubles met with gas-engine driving



Parsons' Turbine Installation (City of London)

in the past will be useful to the student, as enumerated by Mr. A. R. Bellamy.

The following will probably cover the various indictments :—

1. Unsteady driving.
2. Want of balance and cushioning, and, in consequence, vibration.
3. Difficulty in starting large gas-engines.
4. Difficulty of working with "poor gas."
5. Want of more powerful engines.

1. *Unsteady Driving.*—In the early engines this was due to defective governing and want of fly-wheel power. Dealing first with the governing, the three best known methods of governing gas-engines are—(1) controlling the quality of the mixture, (2) controlling the quantity of the mixture, and (3) controlling the number of explosions. The last is generally termed the "hit and miss" principle. The first method was tried in the early engines, and was abandoned because there is not sufficient margin or range between a mixture that gives the best diagram and one that is unexplosive. The second method is one that permits of a considerable amount of discussion. It has the advantage that a greater number of explosions can be obtained when running under light loads; but this is not economical, because it will be understood that the compression of the charge will vary with the quantity unless the area of the compression space or combustion chamber is varied proportionally.

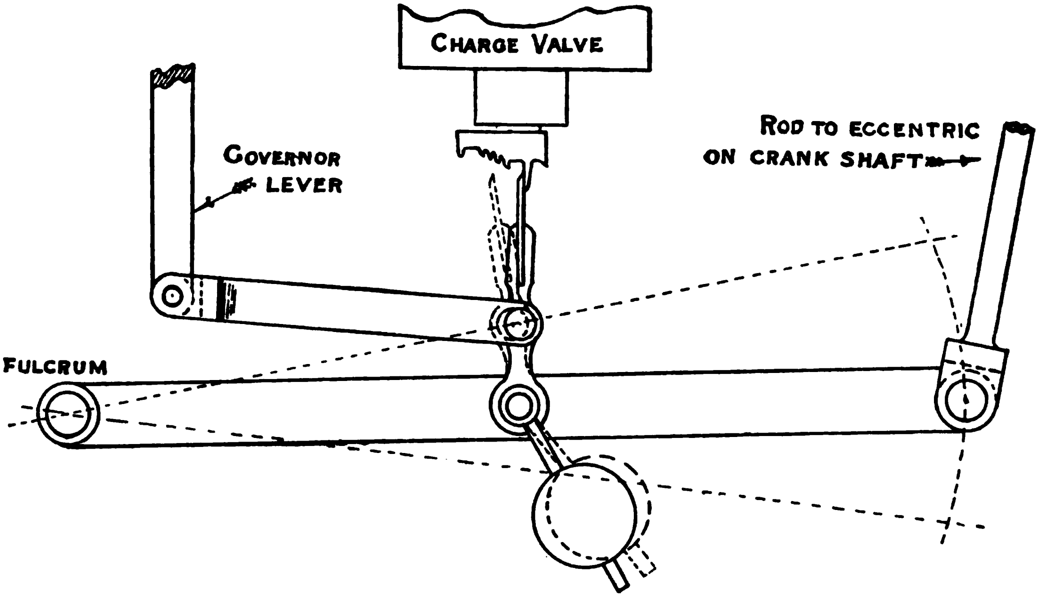


FIG. 28.—Method of Governing Gas-Engine

This latter has never been practically accomplished. A full cylinder charge compressed to the most effective pressure before ignition is the one that gives the most economical results. Fig. 28 illustrates a design of this method of governing which was patented in 1888, and used by the makers of the "Stockport" gas-engine.

2. *Want of Balance, and, in consequence, Vibration.*—Undoubtedly the gas-engine is more difficult to balance than the steam-engine, because, in the Otto cycle, when working to full power, there is only one impulse every second revolution; further, most gas-engines are designed with an open-ended cylinder, and there is no cushion at the forward end, and therefore the piston has to be brought to rest by the crank-pin. This has been overcome to some extent in the double-acting engines like the Korting engine. The want of cushioning is the most serious item; vibration could to a large extent be cured or reduced very much by the Westinghouse vertical design. The author has succeeded in balancing and cushioning a double cylinder horizontal engine.

3. *Difficulty in Starting Large Gas-Engines.*—The old method of starting gas-engines by turning round the fly-wheels by hand was very laborious. Owing to the method of ignition—by the slide valve, which needed careful adjustment—the fly-wheels had to be turned at a good speed, otherwise the engine failed to "get away." If the slide valve was not in good order the time occupied in starting was very considerable. The introduction of tube ignition did a great deal to lessen this difficulty. The makers of the "Stockport" gas-engine used tube ignition at an early date on all their engines, and in consequence the starting was more easily accomplished. With large engines it is, however, impracticable to start by hand, and the method generally adopted is to bar round the fly-wheel to the proper position for starting, as in a steam-engine. An explosive mixture is then obtained in the cylinder, behind the piston, either by allowing gas to enter and mix with the air already in the cylinder—the gas being at a slight pressure will do this if a vent be provided to allow some of the air to escape—or by pumping in either gas, or a mixture of gas and air, into the cylinder. The use of a pump enables a quicker start to be made, as the gas can be introduced at a greater velocity, and also the charge can be compressed before ignition, which increases the force of the initial explosion. After an explosive mixture is obtained it is fired either by a light external to the cylinder, or by means of the igniter on the engine. If a tube igniter is employed, then the tube must be hot before the gas is introduced to the cylinder. In the gas-engine fitted with tube ignition the starting impulse takes place automatically as soon as the explosive mixture is formed, and there is thus very little chance of failure. It is found in practice that this method is simple, reliable, and acts well for

starting gas-engines driving dynamos. Some makers adopt methods which have for their object the firing of a mixture under considerable compression. These are not quite so reliable as the one already described, and the stronger impulse puts a greater strain upon the working parts of the engine. If the engine is required to start under a partial load there may be some advantage, but under such conditions starting by means of compressed air is preferable. Starting by means of compressed air is fairly reliable and easy. It is, however, necessary to have an air compressor, preferably worked by a small gas-engine, and a container for storing a certain volume of compressed air. This adds to the first cost. To start with compressed air it is necessary to connect the cylinder of the gas-engine to the receiver, and to have a suitable valve to allow the air to act on the piston on every "impulse stroke," until the engine gets up to the requisite speed. With double-cylinder engines the air can be applied to one cylinder, and the other cylinder can immediately commence its cycle of operations as when working, except that the compression will be partially relieved by keeping the exhaust valve open longer. This relief of compression is usual in all methods of starting. It will thus be seen that the difficulty of starting large gas-engines has been successfully overcome in more ways than one.

4. *Difficulty of Working with "Poor Gas."*—It is sometimes said that gas-engines often work well with town's gas, but give trouble when working with "poor gas." When this occurs it is not altogether the fault of the gas-engine, which very often receives the blame when the cause of the difficulty is in the gas plant. It is certainly true that there is more need for care when the installation includes a gas plant, but if the gas-engine be properly constructed to work with poor gas, and the gas plant be designed to produce clean gas of about 140 B.T.U. per cubic foot, then with the attention of an intelligent labourer there will be no trouble worth mentioning. Many such installations are in daily use and are working satisfactorily under the care of men who would be incapable of taking charge of a steam plant. The use of Magneto-Electric Ignition has simplified and improved the gas-engines for working with poor gas.

5. Finally, *The want of large gas-engines.*—About ten years ago, the author, in an article in the *Electrical Review*, pointed out that there was far more power going to waste in our blast-furnaces in the shape of gas than all the water-power in Britain, and at that time the demand also arose for large engines for municipal plants; yet our gas-engine makers made no attempt to meet these demands, consequently steam has been in almost all cases the power.

The difficulties are now disappearing before the attacks of younger and independent engineers, and blast-furnace gas-engines are actually now being made of large dimensions. We have already in Vol. III. described the large gas-engines for electric driving developments. The most satisfactory progress is the outcome of experience, and this cannot be obtained without time. The experience of a few weeks or months is insufficient to test the merits of any new development. Suffice it to say, that there are now several makers of gas-engines producing units of 500 h.p. Engines of 150 to 200 brake h.p. manufactured by any of the well-known makers can be accepted as readily as a steam-engine of similar power. It may be said that even the 500 h.p. unit is paltry in size when compared with steam-engines. This may be so, but it should not be forgotten that when the gas-engine first claimed attention about twenty years ago it was little better than a toy, and therefore the progress that has been made in the past augurs well for the future. The Stockport Gas-Engine for large powers is herewith illustrated in Fig. 29, a double-ended engine.

Having now dealt with the debit side of the gas-engine account, it is only equitable to consider the credit side. Undoubtedly the first and most important item is economy in working. Tests were made by independent experts, and no attempt was made by the makers to emulate the example of "trial runs." In the case of a test made at Messrs. Harmsworth's the plant had only just been put to work. The engines were not working at more than three-quarter load, yet the consumption of fuel per brake h.p. per hour equals 1.37 lbs., or per K.W. hour 2.16 lbs. In the test made by Mr. Mathot of the engine erected near Brussels, the total consumption of fuel per brake h.p. per hour equalled 1 lb., and the thermal efficiency with the engine working at 85 per cent. of its full power came out to 18.5 per cent. In the second test made by Mr. Mathot of the "Stockport" gas-engine, working with town's gas, it will be noticed that the consumption of gas at full load was 15.65 cubic feet per effective h.p. per hour, the engine developing 50.2 b.h.p. Town's gas can be taken at an average price of 2s. 6d. per thousand cubic feet. There are a great many towns that supply gas at less than the above price. Assuming 2s. 6d. as an average price, then with an engine developing 50 b.h.p. the cost of gas would work out to one halfpenny per brake h.p. per hour. Allowing 1⅓ b.h.p. per K.W., the cost of gas per K.W. would then work out to .7 of a penny. It will therefore be seen that gas-engines working with town's gas can produce electric current at a cheaper rate than is usually supplied even for motive power purposes from central stations.

It may be urged that the cost price of the fuel that is generally used in gas plants is considerably more than ordinary steam-coal, but within the last few years a great advance has been made in the production of gas from bituminous coal, and at the present time gas-engines are being successfully worked by gas manufactured from

Stockport Gas-Engine

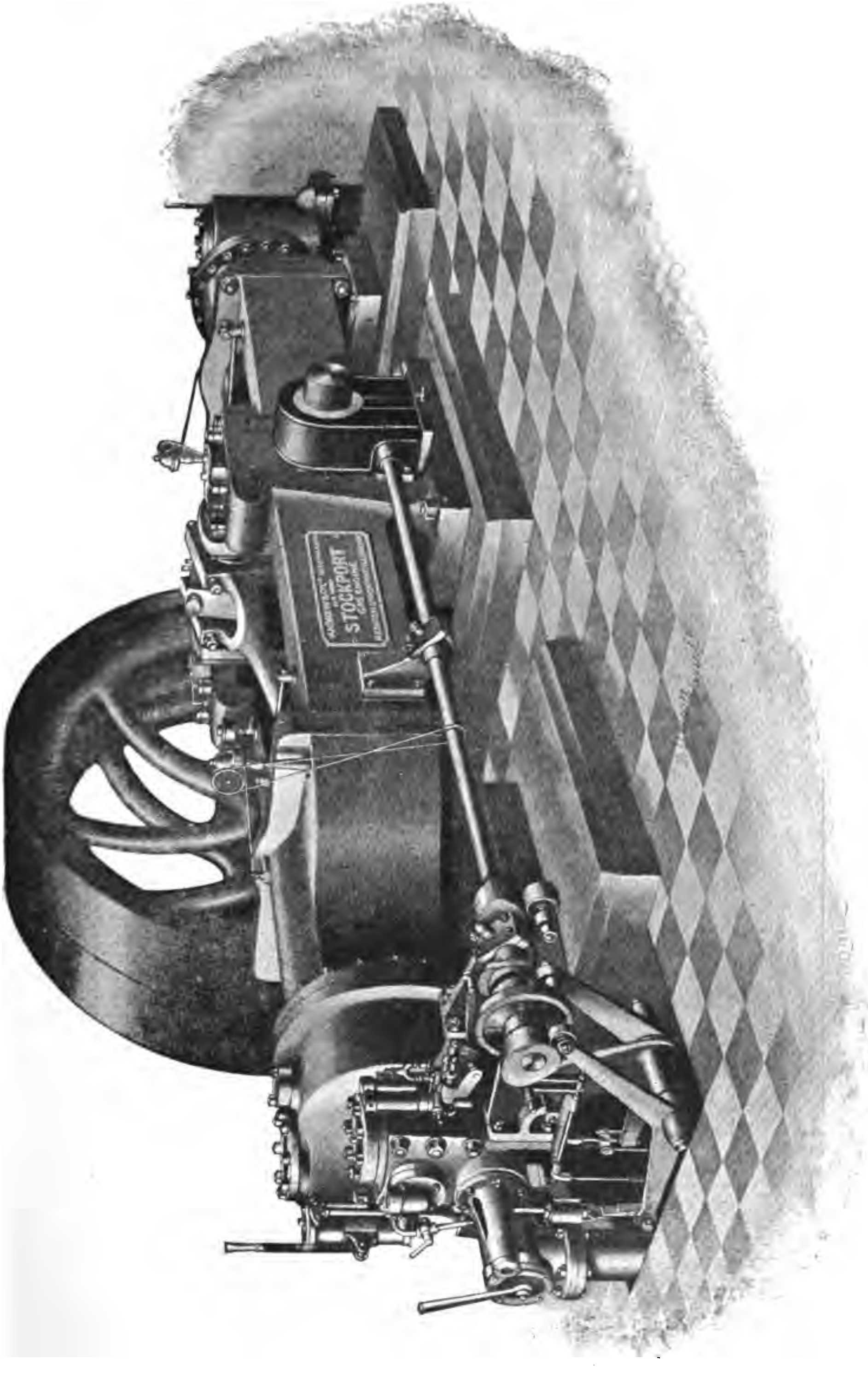


FIG. 29.—Stockport Gas-Engine

bituminous slack of such a poor quality that it would be considered almost unfit to be used for firing a boiler.

The nearest approach to a central station driven by gas-engines is the installation just completed by the Westinghouse Company for the Metropolitan Railway Carriage and Waggon Company, Birmingham, using Dowson Gas Westinghouse Vertical Gas-Engines direct coupled to two-phase alternators. The gas-house, which is large

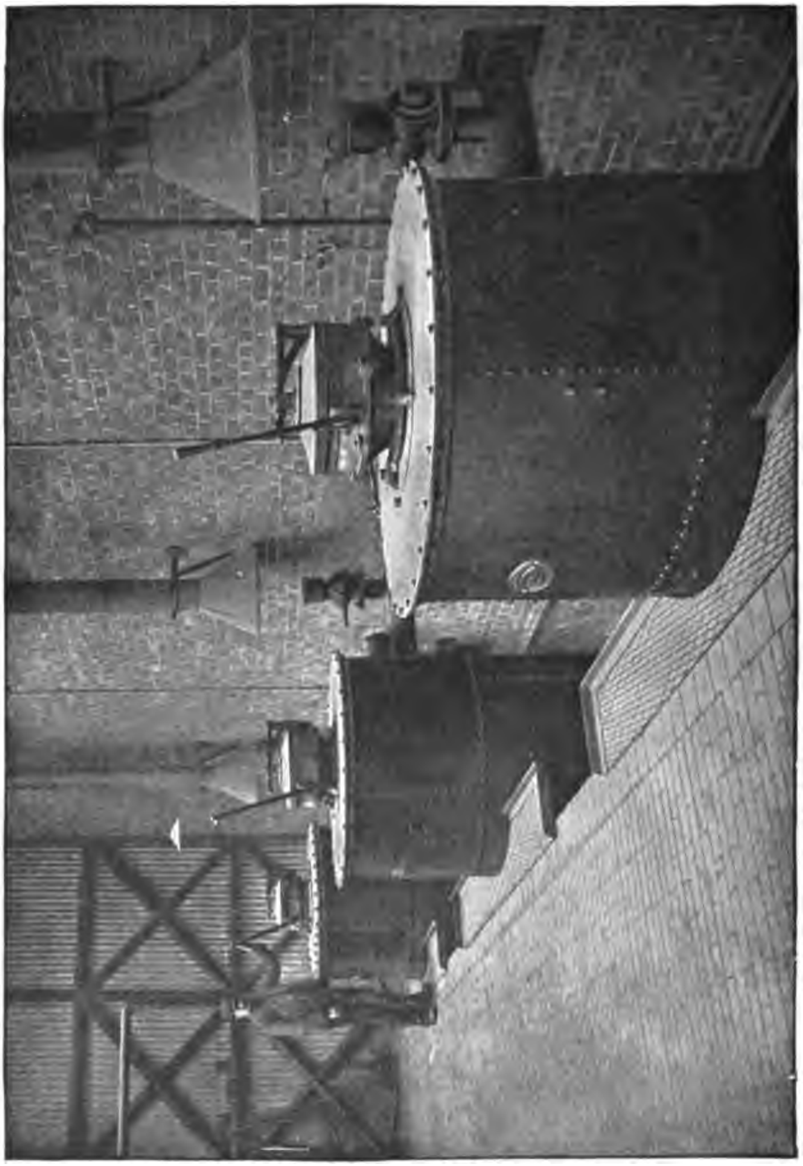


Fig. 30.—Dowson Gas Generators

enough to generate gas for 1000 horse-power, is smaller than a similar power for steam boilers; it is 74 ft. × 20 ft. In this house provision has been made to receive four of the well-known Dowson gas generators (Figs. 30 and 31), three of which are at present installed. The gas is made by passing a mixture of superheated steam and air through a deep fire made with small anthracite coal. In this way the air supports combustion of the fuel, and a high

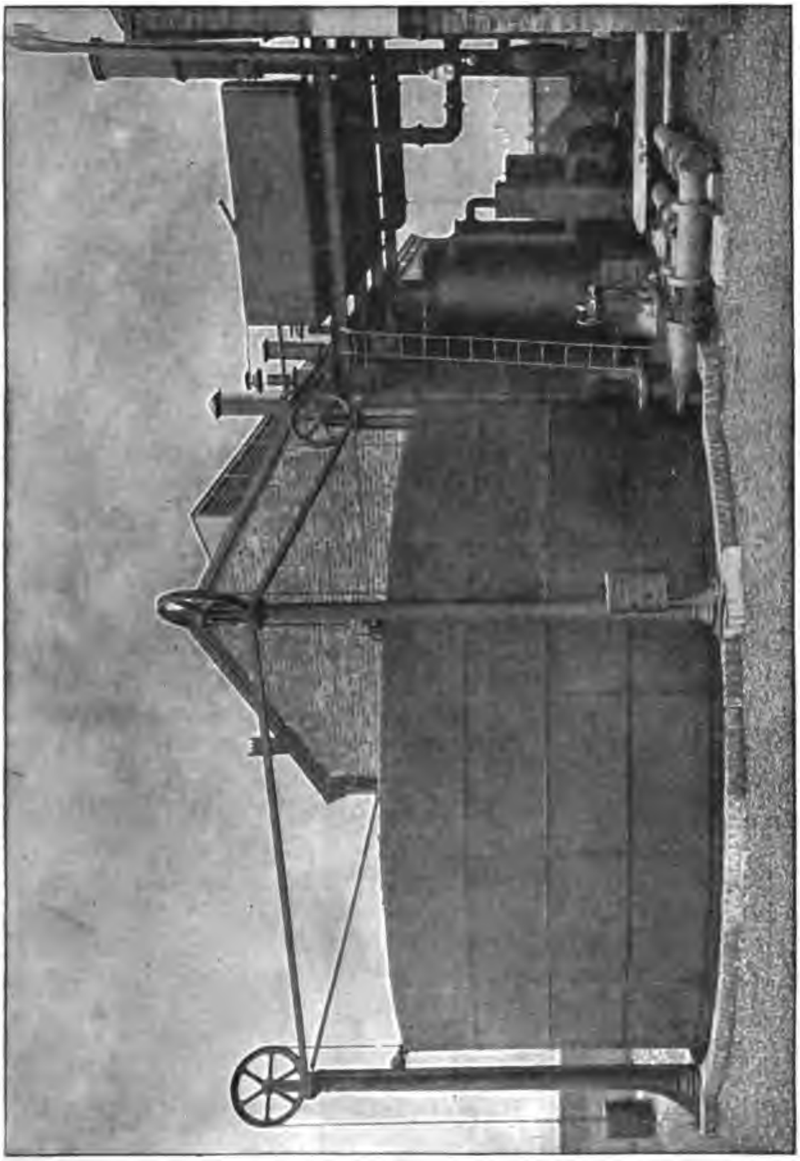


FIG. 31.—Dowson Gas Plant

temperature is maintained, so that the steam is decomposed continuously. The gas produced has a calorific power of about 150 B.T.U. per cubic foot (at standard temperature and pressure), and, as the process is continuous, and not intermittent, the quantity and quality of the gas are fairly constant.

Each gas-generator is capable of serving a maximum of about 250 brake-horse-power. On the top there is a special feeding hopper with valve and cover, so that fuel can be put in without an outrush of gas while the plant is at work. The steel casing of the generator is lined internally with circular firebricks, and the top of the generator is protected by a dome of brickwork under it. The steam pressure used is about 60 lbs. to the square inch, and with this the volume of gas produced in each generator is about 20,000 cubic feet per hour. There are two superheating vertical boilers in the gas-house to supply the gas-generators, and the admission of steam to the latter is regulated automatically by the rise and fall of the gas-holder. In other words, when the engines are fully loaded and the maximum quantity of gas is required, the gas-holder is practically stationary at a moderate height, and this causes a full supply of steam to be given to the generators. When the load on the engines is reduced, an excess of gas is made and the gas-holder rises until it reaches a point when it partly closes the steam-valve and reduces the supply of steam to the generators. This at once checks the production of gas, which is thus regulated automatically to suit a varying rate in the consumption.

When the gas leaves the generators it passes through some cooling pipes, and then through water in a hydraulic box (Fig. 31). The latter not only helps to clean the gas, but it shuts off all connection between the fire in the generator and the other parts of the plant. After leaving the hydraulic box the gas passes through two coke scrubbers, each 3 ft. in diameter by 14 ft. high. On the top of the second coke scrubber there is a small washer of special construction, recently introduced by Mr. Dowson, which materially assists in the cleaning of the gas. Finally the gas passes through a sawdust scrubber, and then into a gas-holder 20 ft. in diameter by 10 ft. deep. When the gas reaches the inlet of the gas-holder it is as cold as the surrounding air, a proof that the cooling part of the plant is as efficient as possible. From the gas-holder the gas passes through a main pipe leading to the engine-house, and is delivered there at a pressure equal to about 1¼ ins. of water.

It may be added that at meal-times and when the works are closed the production of gas is stopped instantly by closing the steam-valve and stopping the admission of steam to the generators. A dead fire is left in the latter, as in a slow combustion stove, and the waste of fuel in each generator during the night is usually only about 3 lbs. per hour.

The engine-room contains three direct-coupled gas electric generating sets (Fig. 32), each with a small electric exciter, and also the auxiliary compressors required, an air compressor for starting the gas-engines, a hydraulic circulating pump for cooling the engine cylinders; the latter two being driven by an electric motor. The main power generators are all three exactly similar in size and construction. The gas-engines are of the Westinghouse vertical, three-cylinder type, each of about 250 h.p. capacity. The cylinders are all of the same size, 19 ins. diameter by 22-in. stroke, and single acting. The three cranks are at 120 degs. with each other, and since each cylinder works on the Otto cycle principle—that is, each piston receives one impulse every other stroke—the crankshaft receives one propelling impulse every two-thirds of a revolution. This fact alone insures a very even-turning moment; but this is further secured by the method of regulating and governing the

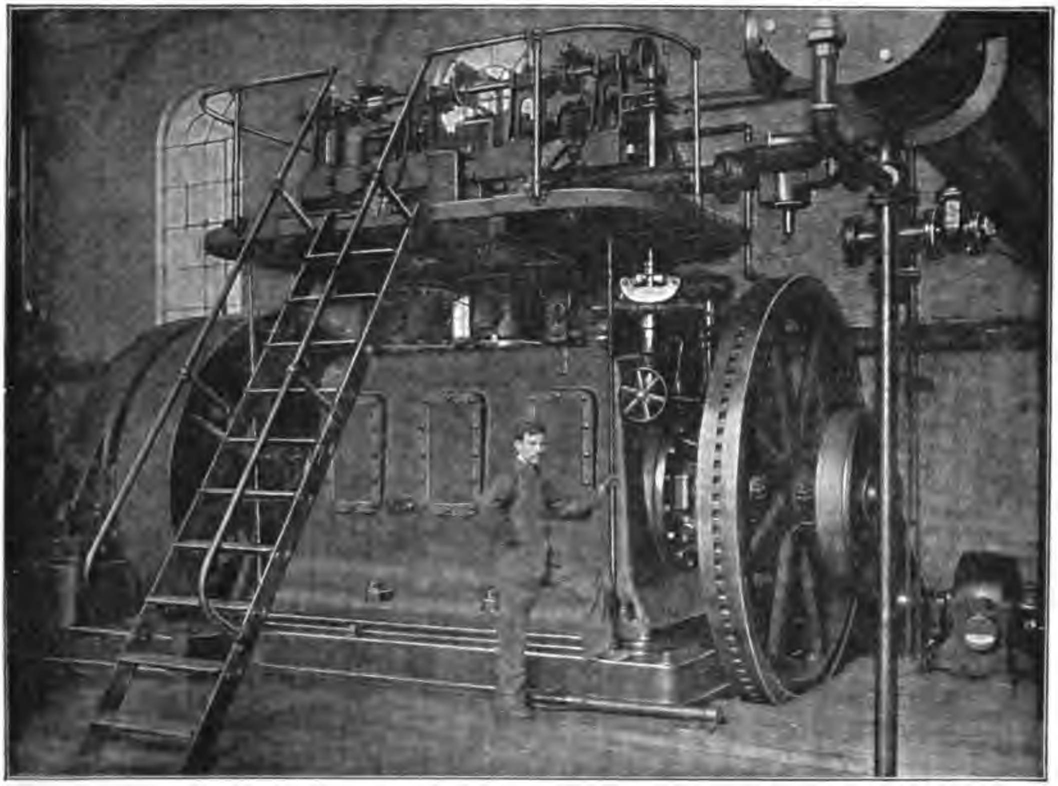


FIG. 32.—Westinghouse Gas-Engine

engine which is adopted. There is only one admission valve to each cylinder, to which the gas and air are admitted in the form of a definite, correctly proportioned mixture. The gas and air supplies feed into a mixing chamber through two independent valves. These valves are arranged for easy and definite hand adjustment, so that only the correct quantity of both gas and air is allowed to pass into the chamber. Thus the best, the most effective, and most economical use is made of the quality of the gas available. Between the mixing chamber and the cylinder admission valves is a valve controlled by a sensitive governor of the fly-ball type. By this means the quantity of the mixture passing from the mixing chamber through the cylinder valves and into the cylinders is directly proportional to the load on the engine, and the best of speed governing at all loads is thereby secured. As a matter of fact, the Westinghouse gas-engine is automatically governed to as fine limits as the best of steam-engines, and at the same time it will be noticed that this governing is accompanied always by the greatest fuel economy. The engine is well balanced in its construction, and is remarkably free from vibration; its exhaust also is practically noiseless. The explosive mixture is ignited by a low-pressure electric spark. The contacts are in duplicate, and are placed in the clearance space in the cylinder heads. The current for this purpose is supplied at starting from a small battery of primary cells, but when the engine is running the supply is drawn from a small magneto-dynamo driven by the engine itself. The engine is started by compressed air, a cylinder of which is kept constantly charged. A small reservoir just outside the power-house supplies the cooling water for the cylinder jackets.

The engines are direct coupled each to a Westinghouse two-phase alternate-current generator of 150 K.W. capacity. The main sets run at a normal speed of 200 r.p.m., and current is generated at a pressure of 220 volts per phase, in which form it is transmitted to the various motors throughout the works. The field of each generator consists of a vast steel ring horizontally divided, into which are cast thirty-six pole pieces projecting radially inward. Each pole piece is built up of soft steel stampings, and carries a coil of the field winding. The coils are machine-wound, and fit loosely over the pole pieces. They are secured in position by set-screws through lugs to the field-ring. This form of construction is shown clearly in the cut. The rotating armature is built up on the cast-steel spider, pressed and keyed on to an extension of the engine main shaft. The armature is bar-wound, the copper bars being threaded through slots in the core, where they are held in position by the overhanging lips of the slots. The armature end connections are of copper strap securely bolted to the ends of the armature conductors. The armature core and spider are traversed by channels, through which a constant stream of air is forced by the rotation of the machine, and very cool running is secured. The overload capacity of the machine is great; it will maintain without undue heating overloads of 50 per cent. for a considerable time, and overloads even up to 75 per cent. for short spaces of time are negotiated without any difficulty whatever. Each engine is provided with two heavy fly-wheels, whereby the speed under variable loads is further maintained constant. Each of the main generators has its own exciter, which is a small multipolar direct-current machine of Westinghouse manufacture, driven by belt.

The following is from a copy of a report by Messrs. Handcock & Dykes on the Harmsworth plant already referred to, and will give a fair idea of the working of a Dowson Gas Plant with Stockport engines.

The tests commenced at 8.45 on the night of September 27. No. 1 producer was started up and ran for twelve hours, when the fire was brought to the same level as at the start. During this time the load averaged 44.87 K.W.

No. 2 producer was then started up and ran until 8.45 on the evening of the 28th, when it was shut down after bringing the fire to the same level as at the beginning. The average load during this period was 40.116 K.W.

At 6 o'clock producer No. 1, which had been "standing by" since the morning, was clinkered, and 266 lbs. of fuel added to bring the fire up to the same level as at the commencement, when it ran until 8.45 on the morning of the 29th, when the trials ended; the average load during the last twelve hours being 37.48 K.W.

At the end of the trial No. 2 producer was clinkered and the produce added to that obtained from clinkering No. 1 the evening before, anthracite being added to bring the fire up to the same level. The total amount of residue from the two clinkerings amounted to 80 lbs. of ashes, 15 lbs. of clinker, 80 lbs. of small coal and 385 lbs. of coal which could be returned for use again.

No. 1 producer was not clinkered at the end of the run test, as the engine was required to run for several hours longer.

In the ordinary way, however, this would have been done at the end of the third twelve hours, when it is fair to assume that the same amount of anthracite, viz. 266 lbs., would have been added, and the same amount, 192 lbs., regained from the clinker. In ordinary working the coal obtained from sifting the clinker would be returned to the generator or would be used up in the boiler for producing the steam-jet for blowing the producers.

Owing to the plant only just having started running, there was no store of this available, and the boiler was worked with coke, the consumption of which was weighed during the trial. The electrical output was measured at the terminals of the dynamos by means of a Kelvin illuminated dial voltmeter, which was checked against the Kelvin standard voltmeter and by a Kelvin ampere gauge at the main switchboard, readings of both being taken every ¼-hour and the load being kept as constant as possible by switching lamps on and off. The variations were comparatively small except towards the end of the test, when owing to various causes it was impossible to switch on quite the full number of lamps required. The speed of the engines varied from 198 to 204 revolutions per minute, and when changing from one dynamo to another the incoming set was run up to speed, the dynamo then put in parallel with the working machine, and the first machine then cut out of circuit; the amount of fuel consumed during the time the machine was being run up to speed and switched into circuit being, of course, included in the amount measured.

The fuel used was best Welsh washed anthracite peas, and was weighed out during the trial in 1½ cwt. lots.

The ignition tubes were heated throughout with town gas, the consumption being 15–20 cubic feet per engine per hour, each engine having double ignition tubes.

The voltage of the machines throughout was approximately the same, the increased voltage required as the potential of the cells rose being obtained by means of a booster driven off the main bus bars, the current going into the cells falling as the voltage rose so as to keep the load on the dynamo constant.

RESULT.

Length of run	36 hours.
Mean load	40.85 kilowatts.
Mean B.H.P.	64.4.

Total anthracite weighed out during run	2520 lbs.
Total actually added after clinkering	532 „
Add allowance for clinkering the third time	266 „
Total anthracite	3318 lbs.
Less amount recovered, 385 + 192	577 „
	2741 lbs.

2741 lbs. equals total anthracite consumption for one generator and engine for three days of twelve hours each, including "standing by," losses of another generator for thirty-six hours, and loss whilst both engines were running together whilst changing over.

Results of Tests

SUMMARY.

Anthracite per K.W. hour . . . . . = 1.86 lbs.
„ „ B.H.P. hour . . . . . = 1.18 „
Coke consumed, total . . . . . . = 448 „
„ „ per K.W. . . . . . = 0.3047 „
„ „ „ B.H.P. . . . . = 0.193 „
Total fuel per K.W. . . . . . . = 2.16 „
„ „ B.H.P. . . . . = 1.37 „

Mr. R. Mathot's tests on a Stockport engine are also of interest, although on a small plant made June 1901. The results are as follows:—

1.	Heating power of mentioned fuel	7520 cal.
2.	Cost of fuel per ton at pit mouth	27.50 fr. (22s.)
3.	Cost of fuel per ton at producer	31.93 fr. (25s. 6d.)
4.	Consumption of fuel per hour in producer	21 kgs. (46.3 lbs.)
5.	Consumption of fuel per hour in boiler	3.18 kgs. (7 lbs.)
6.	Amount of ashes in anthracite	6 per cent.
7.	Amount of steam produced at 4.5 atmospheres per hour	19 kgs. (42 lbs.)
8.	Average effective work on shaft	53 H.-P.
9.	Consumption of fuel for gas producing per brake-horse-power hour	0.396 kgs. (.87 lb.)
10.	Consumption of fuel for steam producing per brake-horse-power hour	0.060 kgs. (.13 lb.)
11.	**Total consumption of anthracite**	0.456 kgs. (1 lb.)
12.	Corresponding steam consumption at 4.4 atmospheres	0.366 kgs. (.8 lb.)
13.	Pressure of gas at engine	30 mm. (1.2 in.)
14.	Amount of water for cooling of cylinder, flowing in at 20 deg. C. and running out at 45.5 deg. C. per brake-horse-power per hour	23.25 kgs. (52 lbs.)
15.	Amount of heat absorbed by cooling	592.8 cal.
16.	Average of initial explosive pressures on piston	22 kgs. per sq. cm. (313 lbs. per sq. in.)
17.	Mean average of average pressures on piston	4.9 kgs. per sq. c.m. (69.7 lbs. per sq. in.)
18.	Average indicated work with 85 per cent. of explosions	63 I.H.P.
19.	Corresponding mechanical efficiency	84 per cent.
20.	Corresponding effective electric work	31.950 k.w.
21.	**Cost of horse-power for anthracite**	0.0145 fr. (.145 of 1d.)
22.	Cost of kilowatt-hour in anthracite	0.024 fr. (.14 of 1d.)
23.	Effective electric work developed per each brake-horse-power	602.8 watts.
24.	Thermal efficiency with 53 brake-horse-power under 85 per cent. of explosions	18. 5 per cent.

The following remarks made in this report are instructive as regards the attention required to the engines and producers.

1st, The ignition, inlet, and exhaust valves require grinding once a week; the gas valve, hydraulic box, and overflow tank require cleaning out twice a week.

2nd, The fires in the boiler and gas producer can be banked every night, the latter requiring drawing twice a week.

One man suffices for looking after the plant. Wood-fibre is used instead of sawdust in the first scrubber—this requires replacing once a fortnight; the coke in the second scrubber is good for two months. Both can be again used after drying.

Now it must be remarked that considering the gas-engine as an internal combustion engine, the total consumpt of fuel, although very creditable in itself, is surprisingly great, but much is due to the small size of the plants.

Also the thermal efficiency of gas-engines as shown, 18.5 per cent., must be capable of great improvement.

The fact is that the gas-engine does not entirely fulfil the conditions of working in a perfect internal combustion engine; if it were fed by natural gas it would be nearer the theoretical efficiency, but being fed with artificial gas, all the heat in the boiler and producer furnaces is lost—in fact only part of the fuel, the gaseous part, is utilised internally in the engine; the solid fuel is burned externally, producing no power. The Dowson gas producer and gas plant has been used in a central station at King's Lynn, and also at Leyton, in London, with what results cannot be definitely ascertained.

Better results, as far as cost goes, will be obtained from the gas producers using ordinary bituminous coal; some of these, such as Wilson's, Mond's, Duff's, and others, are now coming forward, and on a large scale promise to reduce the cost of gas to a very small value.

In the larger engines more recently made the quantity of gas required per indicated horse-power hour has ranged from 80 cubic feet down to 52.1, the powers of these engines having been respectively 160.4 and 489 indicated horse-power, and the quality of the gas being practically the same in all cases. The solid fuel consumption per indicated horse-power hour is not so readily ascertained on account of uncertainty as to the volume of gas yielded by the producers per ton or per lb. of fuel. There seems to be, however, no reason to doubt that it is now possible to develop power in large gas-engines with producer-gas on a consumption of bituminous slack, equal to from 0.95 to 1.0 lb. per indicated horse-power hour. This is probably not the limit, because increased experience of the working of large gas-engines will almost certainly lead to further improvement.

There are undoubtedly some difficulties in applying ordinary producer-gas to engines, especially to those of large power, as the volume of gas used increases in a greater ratio than does the cooling surface of the cylinders. The large volumes of gas which have to be used, and the high temperature of combustion, make it difficult to keep down the temperature of the metal of cylinders and pistons, and to prevent pre-ignition and other troubles. Much has been done to improve the ignition, compression, and scavenging arrangements, and the cooling of cylinders and pistons, and no doubt further advance will be made along these lines, as well as in methods of recovering some of the waste heat carried off in the exhaust gases. Further accuracy in determining results would be ensured by continuous or frequent estimation of the heat value of the gases by means of Junker's calorimeter, which for this purpose is *sui generis*, and by more precise information as to the quantity of gas produced per ton of fuel.

According to Mr. Bryan Donkin, we may take the heat value of illuminating gas roughly at 584 B.Th.U. per cubic foot. That of producer gas made from coal varies, according to one authority, from 144 to 165 B.Th.U., but according to another is properly 190 B.Th.U.—the analysis quoted on page 36 gives a heat value of about 183 B.Th.U. per cubic foot. The gas from "Mond" and from "Dowson" producers is given as equal to 150 B.Th.U. That is a favourable estimate of the gas made from "Mond" producers using slack coal, the ammonia being recovered from the gas (125 being about the usual figure), but is about the normal value of producer-gas from coke or anthracite. The gas from blast-furnaces using coal is equal to about 137 B.Th.U., and from coke furnaces it averages about 100 to 110.

In comparison with average steam-engines where producer-gas is burned under the boilers to generate steam, 100 cubic feet of power gas burned directly in a gas-engine cylinder will yield as much power as 400 feet burned under the boilers. The consumption of fuel in larger gas-engines using power gas has now been brought under 1 lb. per i.h.p. per hour.

Combined with it there arises the question of the distribution and cost of power gas. Schemes are put forward for monopolising large tracts of country in the interests of one form of gas producer, as far as the right to distribute the gas to consumers is concerned. But that need not deter individual consumers within such districts from supplying themselves with producers for their own requirements, especially as by so doing they will obtain much cheaper gas.

The cost of production is barely above one penny per 1000 cubic feet with expensive coal. Thus, if we take coal at 10s. per ton in a producer gasifying 10 cwt. per hour, and working 60 hours per week, the quantity of gas yielded per ton being taken at 150,000 cubic feet, the labour cost as equal to 1s. per ton, and the charges for interest and depreciation at one quarter the cost of the coal, we have per 1000 cubic feet:—

		d.
Coal	=	.80
Labour	=	.08
Interest and depreciation	=	.20
		1.08

Of course with the cheaper dross which would most commonly be used, the cost of the gas is less, and as the labour cost has been arrived at by taking 30s. per week as the wages of one man for one 10-cwt. producer, in the usual case in which several producers are at work together, the labour charge will be proportionately less.

For further information the reader is referred to Mr. F. J. Rowan's paper on "Producer Gas," read before the institution of Shipbuilders and Engineers, Glasgow.

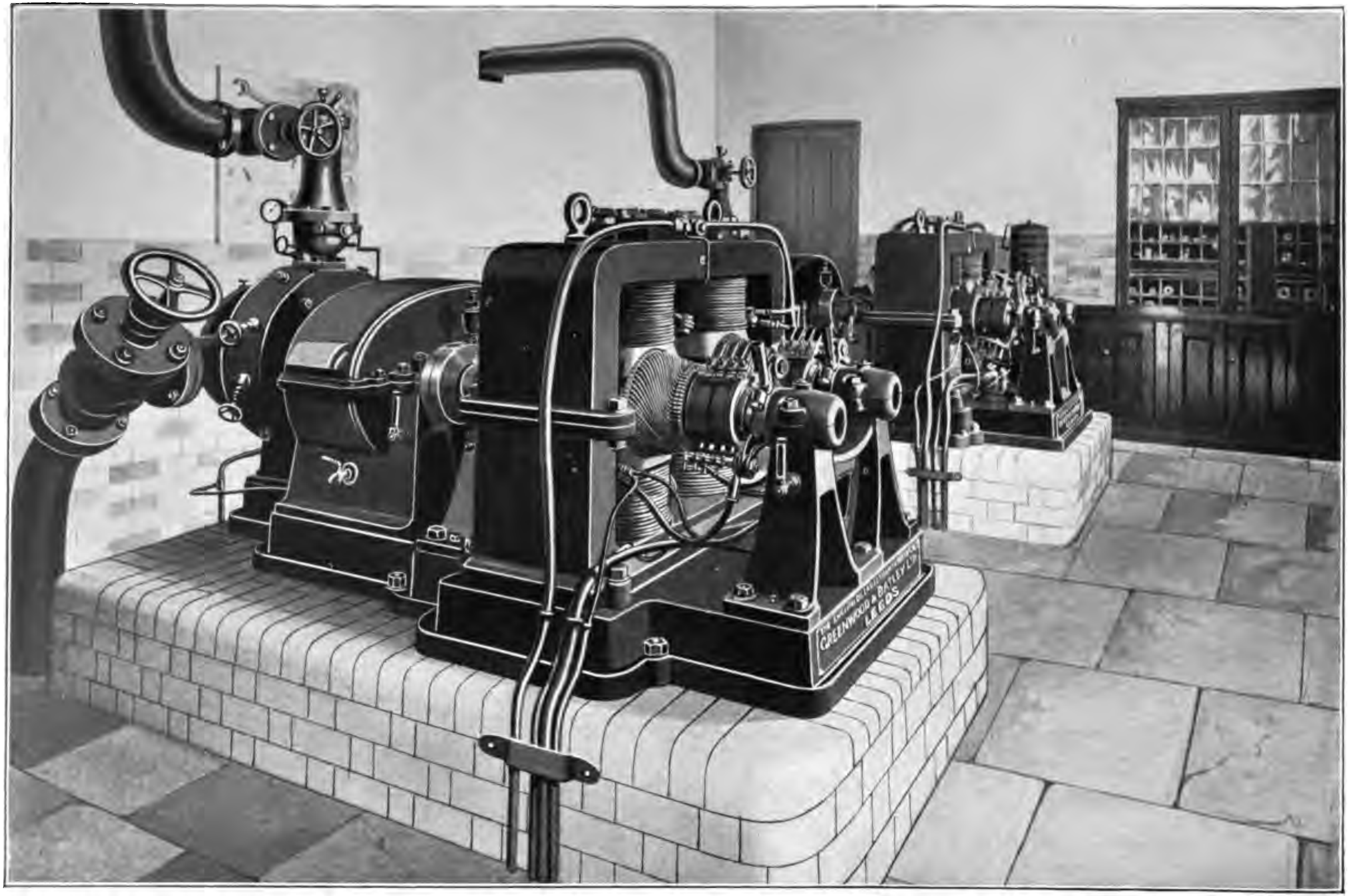
The gas plant has been fully considered, because it is the most direct, cheapest, and simplest method known for producing electrical energy from fuel. It has much to recommend it. If the plant is unsightly and perhaps odorous, it has the advantage over steam that it need not be on the same site as the electric generators and engines, but may be a mile or so away out of the town or city.

That there is room for further improvements in gas power is obvious from the fact that the fuel consumpt is still about 1 lb. per i.h.p., while a good steam-engine is about 1.4 lb. in consumpt, and the improvements are to be made both on the engines and in the gas producers.

Oil, as a fuel for large engines, has some possibilities. In the Ackroyd engine heavy petroleums can be used and gasified in the cylinder. It is claimed for some of these engines using heavy oils, that a brake horse-power can be obtained for one farthing per hour. Nothing on any large scale has been tested. They have, however, many good points for the small power in which they have been hitherto tried.

Solid fuel or rather dust has also been proposed. We all know that coal-dust mixed with air in dry mines has exploded with disastrous results. The difficulty to be overcome in using a coal-dust and air mixture in the engine, is chiefly that due to the production of ashes and tar in the cylinder. If these difficulties could be mastered we would have truly an internal combustion engine, in which all the heat of the fuel would be liberated in the engine.

Motors and dynamos and their accessories have now reached a stage requiring little attention from electrical engineers in design or construction; but there is still a large field for research and improvement in the better half of the electric generator, the



De Laval Turbines and Twin Dynamos

heat-engine. There is a good deal of truth in a suggestion made by Mr. W. H. Booth that the explosion in gas-engines takes place at the wrong time, and should take place after the piston has travelled some part of the out-stroke and acquired some speed, instead of on the dead centre.

The Akroyd oil-engine by Messrs. Hornsby has been recently tested with a new supply of cheap oil called fuel oil, as it is of not much use for any other purpose. It comes from Texas and Russia; the engine is shown in Fig. 33, and is described as follows in a reprint from *Engineering*:—

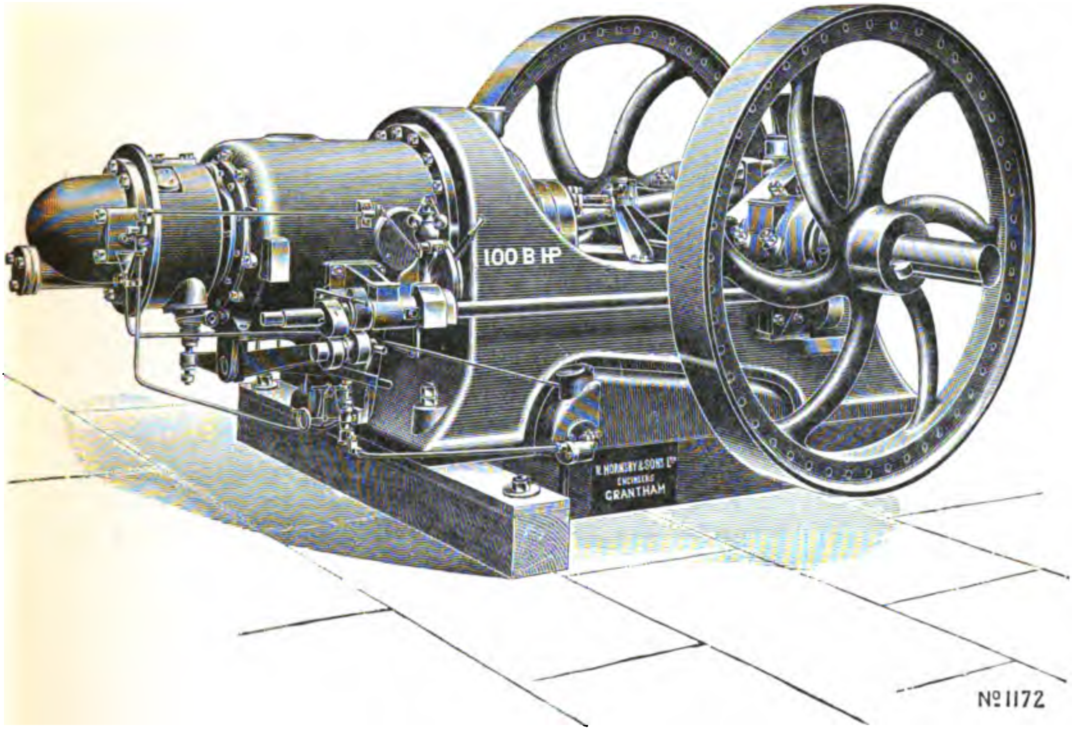


FIG. 33.—Hornsby-Akroyd Oil-Engine

"The engine illustrated has been constructed by Messrs. Richard Hornsby & Sons, Limited, of Grantham. It is of 125 brake-horse-power when working with American oil, and of about 100 horse-power with Russian and Texan residue; and is, we understand, the largest oil-engine ever built. The Texan oil has now been put on the English market by the same company which is supplying Borneo oil, and there is the prospect that the supply will be continuous. If this be so, the oil-engine will enter upon a new stage of its development. Hitherto large sizes have not been commercially possible, because the cost of fuel was prohibitive.

"But with oil at 1¾d. a gallon in tank waggons alongside the Thames, and at 2½d. a gallon delivered in the Midlands, the fuel question assumes another aspect. The engine shown above, running at full power, burns .764 pint of oil per brake-horse-power per hour, which is equal to .191d. at the price given."

These figures are realised at a test, and are quite within the bounds of what might be reasonably anticipated. The oil has a specified gravity of .920, a calorific value of 19,000 British thermal units, and a flash-point of 172 deg. Fahr. It is very dark, almost black, and fairly thick, so that it is not at first sight a likely fuel for oil-engines. The Hornsby-Akroyd engine, however, is so entirely free from complications and narrow passages that no difficulty is experienced in dealing with this oil. At each alternate revolution a small quantity of oil is sent by the pump (to be seen underneath the valve levers) to the spray nozzle at the side of the vaporiser, and is injected into that vessel, which is worked at a heat which is faintly red in the dark. The oil is vaporised during the outstroke of the piston, and the charge is compressed on the instroke, until it is finally fired by the heat of the vaporiser, without an ignition tube or external lamp, when the crank reaches the back centre. It is only the hemispherical end of the vaporiser which gets hot. The part between it and the cylinder is water-jacketed, as is also the cylinder and the piston. The inlet and outlet water pipes from the piston can be seen projecting from the mouth of the cylinder.

The regulation is effected by a governor, which does not cut out the explosions, but opens a by-pass valve, and allows a part of the oil from the pump to flow back to the reservoir. Even when running light the engine maintains its full number of explosions per minute. It ran thus for an hour upon 28½ lbs. of oil—or 31 per cent. of the 91.7 lbs. of oil it used during an hour's run at 104.3 brake-horse-power. An ordinary steam-engine does not show a better economy at light load.

To return, however, to the question of cost. This oil-engine, running under test conditions, costs .191d. per brake-horse-power hour; a steam-engine, using 3 lbs. of coal at 13s. 4d. a ton, would cost .2d. per horse-power; and a gas-engine, using 17 ft. of gas at 2s., would cost .4d. There are, however, many charges connected with engines in addition to fuel, and test conditions are seldom attained. Such charges are difficult to estimate, and different people would assign different values to the various items. Below we give a set of estimates prepared by Messrs. Hornsby which does not err in favour of the steam-engine :—

100 *Brake-horse-power Engines. Comparative Costs of Running.*

	Hornsby-Akroyd Oil-Engine.			Gas-Engine, Town Gas.			Gas-Engine, Power Gas.			Compound Non-Condensing Steam-Engine.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Interest, depreciation, attendance, &c.	219	14	0	170	7	0	179	16	3	323	8	0
Oil, gas, or coal and water for 300 days of 10 hours	312	10	0	540	0	0	359	17	0	458	5	0
Cost of oil, gas, or coal and water per brake-horse-power per hour	0.250*d.*			0.432*d.*			0.288*d.*			0.367*d.*		
Total cost per brake-horse-power per hour	0.426*d.*			0.569*d.*			0.431*d.*			0.625*d.*		

The above costs are based upon—

Texas liquid-fuel oil for the Hornsby-Akroyd oil-engine at 2½d. per gallon. This oil is at present being delivered in tank waggons alongside the Thames at 1¾d. per gallon.

Town gas is taken at 2s. per 1000 cubic feet, and anthracite coal for producer-gas at 25s. per ton.

Steam coal is taken at 12s. per ton and water at 6d. per 1000 gallons.

The cost of power gas includes interest, depreciation, and attendance at producer, in addition to fuel.

The Premier gas-engine has also been described and illustrated in the *Engineer.* Fig. 34 represents the tandem engine of 500 horse-power.

The engine is of the positive scavenger type, the inclined cylinder on the top being the scavenging pump. Each explosion cylinder works on the four-stroke cycle, and the explosions alternate in the cylinders, thus giving an explosion at every out stroke and a compression at each back stroke. That is to say, when one cylinder is making its explosion stroke the other is making its suction stroke; and when one is making its compression stroke the other is making its exhaust stroke. Towards the end of the exhaust stroke the admission valve is opened, and the air compressed by the scavenging pump is forced through the combustion chamber and continues to flow through while the crank turns the centre. The pipe shown leading from the scavenger pump communicates with the admission valves of both cylinders. An air inlet valve admits air to this pipe, and through it to the scavenger pump, and to that explosion cylinder which happens to be making its suction stroke at any one moment. The gas is admitted through a separate valve into a mixing chamber,

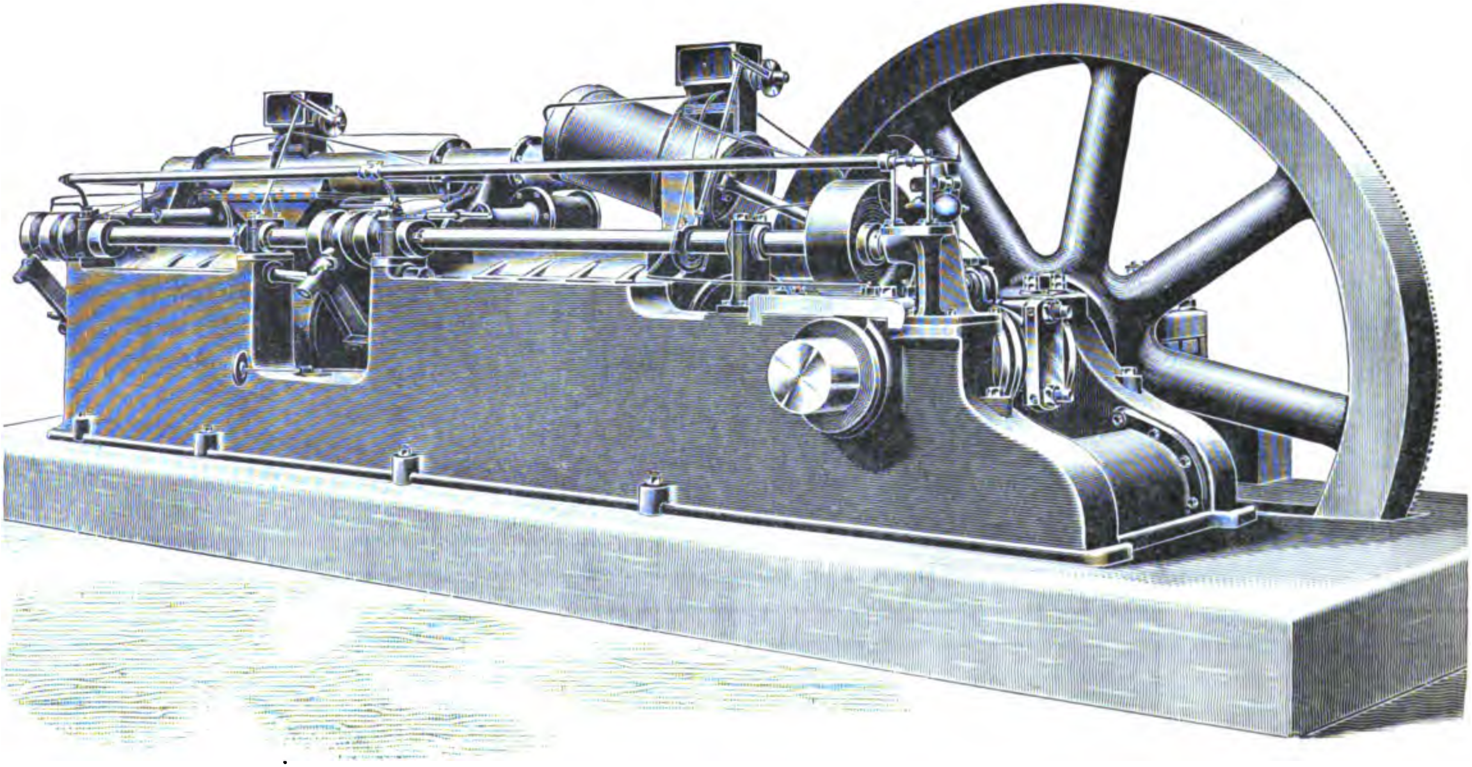


FIG. 34.—Premier Gas-Engine, 500 H.P.

through which the air passes on its way to the motor cylinder. The gas valve has a variable lift, between certain limits, and hence the richness of the charge can also be varied within certain limits. Beyond these limits the gas is omitted.

It will be noticed that a long shaft of large diameter goes from end to end of the engine. This receives its motion through worm gearing actuated by the main shaft. In the engraving this gearing is shown covered with a protection plate. The shaft performs all the motions necessary to the working of the engines. For example, the admission and exhaust valves are worked from it, and it will be noticed that the valve levers are actuated by means of cams, so that a positive opening and closing is insured, and springs are entirely done away with. The valves are placed in the cylinder covers. Both the exhaust valves and the pistons are water cooled. The method of bringing about the latter is by means of a hole bored longitudinally in the piston-rod, and attaching to the latter, at a place where access is made to the longitudinal hole by a cross hole, a rocking lever connected to the water supply through a hinged joint, the reciprocating motion of the piston permitting of the circulation of the water. The governor is also actuated by the horizontal shaft already mentioned as working the valves, and another smaller shaft or spindle worked by the governor controls the gas admission on the hit-and-miss principle.

The ignition is by electricity and is in duplicate, the sparking points being so arranged that one set can be taken out, cleaned, and replaced while the engine is running at full power. This feature is the subject of a patent, as are many other points about the engine. When we saw the plant running there was a small dynamo bolted to the top of the bed-plate, and driven from a pulley on the main crank shaft.

The dimensions of the engine are :—

Diameter of cylinder .	27 inches.
Stroke ,, ,, .	27 ,,
Diameter of fly-wheel .	12 feet.
Over-all length . .	27 ,,
Speed	150

In cases where the gas-producers are at a distance from the engines, as they very well might be in electricity works, it is interesting to note the power which a given pipe would convey from one to the other point. For this purpose we may quote Professor Unwin in his Howard Lectures of 1893, since published in book form by Longmans, Green & Co.

Transmission of Gas

At ordinary gas distribution pressures of 2½ inches of water and a distance of about one mile the figures are:—

A.—Lighting Gas.

Diameter of Main in inches.	Initial Velocity in Main, feet per second.	Cubic feet of gas delivered per hour.	H.P. at 26.5 cubic feet per h.p. hour.
6	9.59	6,782	256
12	13.57	38,350	1,447
24	19.19	217,100	8,189
36	23.50	598,000	22,560

B.—Dowson Gas.

Diameter of Main in inches.	Initial Velocity in Main, feet per second.	Cubic feet of gas delivered per hour.	H.P. at 90 cubic feet per h.p. hour.
6	6.73	4,758	53
12	9.52	26,910	299
24	13.46	152,300	1692
36	16.48	419,600	4662

But the gas may be transmitted with advantage at much higher pressures in very small main pipes. For instance, the 12-inch pipe would transmit 5000 h.p. if we raised the pressure only to 12 inches of water, for lighting gas; for Dowson gas, a 24-inch pipe would, under the same pressure, transmit 5000 h.p.

Enough has been said to show that there are open to the electrical engineer many methods of accomplishing his ends in the most satisfactory manner. The general tendency among power users is to follow their leader, to do what some one else has done, and deputations of municipal committees and their engineers go off to the continent of Europe and to the United States to learn the latest improvements in dynamos, engines, tramways, and railways, as if the home manufacturers and engineers were of no account whatever. We are, however, progressing in the matter of prime movers, and the adoption of improved turbines for steam, gas-producers, and large gas-engines puts us in a better position than hitherto for the more general adoption of electrical transmission of power in factories, and I conclude this survey of the prime mover question and conversion of fuel energy into electrical energy by quoting the very interesting figures given by Mr. Herbert A. Humphrey in his remarkable paper to the British Association at Belfast, 1902:—

"The development of large gas-engines which has taken place during the last few years has but few parallels in the history of engineering enterprise. Gas-engines of 1200 h.p. and 1500 h.p. are already working, and others of 2000 h.p. to 4000 h.p. are being constructed. In the Paris Exhibition of 1900 the 600 h.p. Cockerill gas-engine created much surprise, but now the makers have in hand an engine of 2500 h.p., and are quite prepared to build a 5000 h.p. gas-engine.

"In England the first gas-engines above 400 h.p. were only started in the year 1900, and they worked with Mond gas. One was a 450 h.p. Crossley engine, and the other a 650 h.p. 'Premier' engine; both engines had two cylinders, and were direct-coupled to large dynamos supplying current for an electrolytic plant at Messrs. Brunner, Mond & Co.'s works at Winnington. Additional gas-engine plant is now being added, and all the dynamos work in parallel. At the present time (August 1902) the two leading English manufacturers have delivered, or have under construction, 51 gas-engines, varying in size between 200 and 1000 h.p. Of these Messrs. Crossley Brothers, of Manchester, supply 28 engines, having an aggregate of 8300 h.p., or an average of 296 h.p. per engine, and the Premier Gas-Engine Company, of Sandiacre, Nottingham, supply 23 engines, with a total of 9300 h.p., giving an average of 404 h.p. per engine. These two makers collectively supply 17,600 h.p., and of this power 12,500 h.p. is for driving dynamos.

"This is a striking proof of rapid progress, but we have to look abroad for the great achievements in this direction. Neglecting all engines below 200 h.p., we find that Messrs. Körting Brothers and their licencees have made, or have under construction, 32 gas-engines, with a total of 44,500 h.p., averaging 1390 h.p. per engine. The Société Anonyme John Cockerill, of Seraing, and their licencees come next with 59 engines, having an aggregate of 32,950 h.p., so that the average size of the engines built by this firm is 558 h.p. The Gazmotoren Fabrik Deutz takes the third place with 51 engines, developing collectively 20,655 h.p., and are followed by the Deutsche Kraftgas Gesellschaft and licencees working under the Oechelhauser patents, with engines numbering 28 and giving 16,900 h.p. Table I., page 378, gives a classified list of these and other large gas-engines, and shows the remarkable total of 327 gas-engines, capable of supplying 181,605 h.p."

The distribution and transmission of power to machinery in factories is perhaps the most important work of the electrical engineer outside of municipal systems. There is, however, the question of transmitting large quantities of electrical energy from one centre to distant points. The simplest case is that where the generating machinery is some miles distant from a factory where the power is to be utilised. Here we have a generating station and a receiving station only to deal with. Several instances of successful installations of this kind exist on the Continent and in America, where distant water powers are available.

As in this country, some municipal stations transmit energy in considerable quantities from central stations to outlying suburbs.

Then we have the more ambitious schemes for transmitting energy from large plants to many centres for consumption, the idea being that towns, large factories, railways and tramways, will take a supply in bulk from these centres rather than work a generating plant of their own.

There is no difficulty in setting up the generating plant in any of these schemes. It consists of the ordinary machinery, either continuous current or alternating. The difficulty here is to find a prime mover which can be used to generate a unit cheaper than it can be made by the intended consumers themselves on the spot. In the case of a high waterfall it may be possible to get a unit for less than it can be got by any other means, and therefore its power becomes of value even if it has to be carried a long distance. Power gas may be had cheap at blast-furnaces, or at the pit mouth, by converting cheap slack into gas, and from these points the power may be transmitted to a distance with profit.

If the generating plant requires fuel, and water, and land, then it comes to be a question simply as to how much less these commodities cost on the proposed site, compared with the cost of the same thing on the site of the consumer's premises, for the difference of cost in favour of the long-distance transmitting station is all that can be allowed for the costs of transmission, for the reduction offered to the consumer upon his cost of generating on the spot, and for profit to the investors in the long-distance transmission in bulk scheme. When 1000 h.p. units are reached there is no gain to be had due to mere dimension; it is even doubtful if there is any gain over 500 h.p.

The cost of transmission is unknown in this country beyond what is known about municipal distribution mains, and that is no criterion to accept for transmission in bulk to long distances, as the distances are not great, and the amounts transmitted small comparatively.

For small plant, as in first case between one point and another, continuous current may be used up to 3000 volts or perhaps more, transforming down by a dynamotor at the receiving end to 200 volts for motors and lights. With continuous current the transmission cables may be insulated underground. There is no inductive or capacity troubles whatever.

The transmission is usually from a water power, and the machinery is simple, consisting of a turbine of the Pelton or other high-speed type coupled to a dynamo direct, such as is shown in Fig. 35. The dynamo should be series wound, and as perfectly insulated from earth as possible in its windings and commutator, while the carcase with which any one might come into contact with may be earthed; the coupling should be one of the insulated types between turbine and dynamo.

The receiving station consists of a series motor coupled by an insulating coupling to an overcompounded generator, overcompounded to compensate for drop in speed of the motor proportional to the load. This combination is shown in Fig. 36.

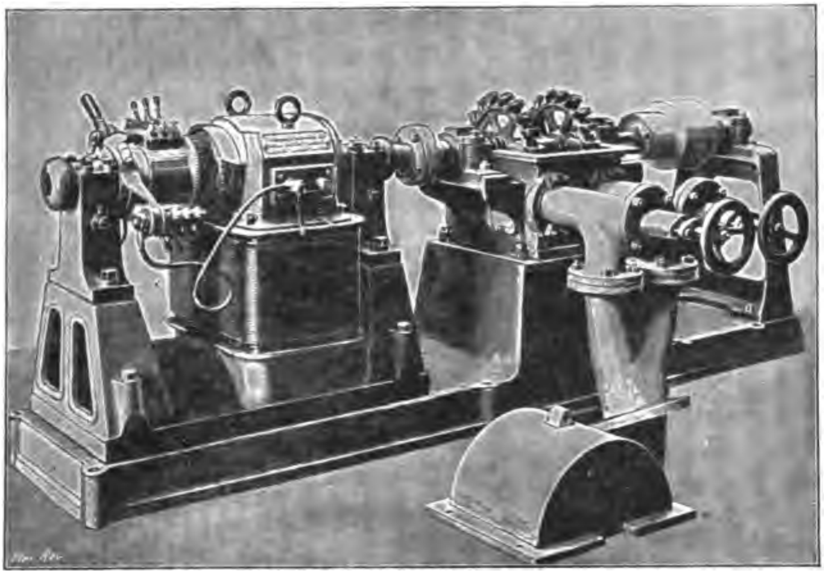


FIG. 35.—Direct Coupled Pelton Turbine and Dynamo

In order that the speed of the motor should be as nearly as possible constant at all loads within its limits, the characteristics of the motor and dynamo should fit each other in a manner best explained by a diagram first given by Mr. G. Kapp. In Fig. 37, O.E. represents the characteristic of the generator at a constant speed of, say, 800. O.e. represents the characteristic of the motor at same speed. The ordinates of curve O.e. therefore represent the counter electromotive force of the motor. Thus to a current O.C. will be opposed an electromotive force C.B., to a current O.C_1 will be opposed an electromotive force C_1B_1, and so on. In the dynamo the electromotive force corresponding to the current O.C. is C.D., and that corresponding to O.C_1 is C_1D_1. Draw O.R. under such an inclination to the horizontal that the tangent of the angle R.O.X.

represents to the scale of the diagram the numerical value of the sum of the resistances (R. + r. + C.) of dynamo, motor, and line respectively. Then the E.M.F. lost in these resistances is for current O.C. equal to C.A., and in O.C_1 equal to C_1A_1, and so on. The ordinates between the straight line O.R. and the curve O.E. represent the counter E.M.F. which must be developed in the armature of the motor at various currents. If the current is O.C. the counter E.M.F. is A.D., and if O.C_1 the counter E.M.F. is A_1D_1, and so on.

Now the counter E.M.F. of the motor at the given speed is given by curve O.e., and it can be seen that if the ordinates of this curve are for every current equal to the ordinates contained between O.R. and O.E., then the motor fits perfectly the requirements of the generator and it will run at constant speed. The motor will maintain that speed whether the current is O.C_1 or O.C., provided $C_1A_1 = B_1D_1$ and C.A. = B.D.

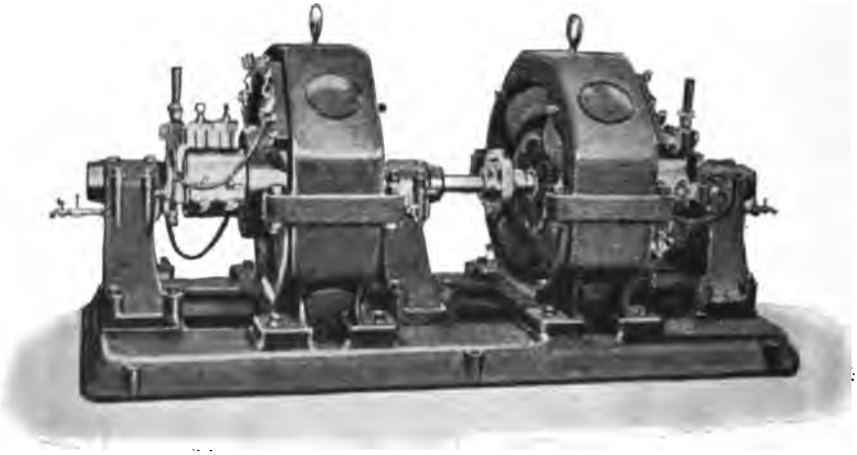


FIG. 36

In brief, the motor counter E.M.F. must fall off more rapidly than the E.M.F. of the generator as current increases with increased load. The best way to secure this is to have less magnetic resistance in the field of the motor than in the field of the generator.

By careful design the speed of the motor under these conditions will not vary more than 3 per cent.

The line may be a very small conductor, and may consist of a high-pressure concentric cable with covering of metal earthed, so that only one insulated conductor is in use, or an aerial line may be used if not carried over public roads or places. This simplest of long-distance transmission (shown in diagram, Fig. 38) has been very successful for moderate water powers in Switzerland up to about 4000 volts and 100 horse-power or thereabout, and two or three miles distance. For larger powers and longer distances the alternating plant is the only possible system. Any power over 500 horse-power and distance over ten miles must be transmitted by alternating currents, preferably three-phase currents. Pressures from 10,000 to 30,000 volts have been experimented with for long distances, and success has been practically achieved at 20,000 volts. But such high pressures are not possible with ordinary underground cables: no insulation could be depended upon; only aerial wires on special porcelain oil insulators can be trusted at pressures over 10,000 volts. Tests made by the Westinghouse experts proved that a considerable loss takes place between wires in the air when the pressures exceed 20,000 volts, and at 30,000 volts a length of wire 540 feet only lost 1200 watts by side discharges. It is evident that there is a limit to the voltages to be used in practice, and probably, all things considered, 10,000 volts is as high as can be commercially successful.

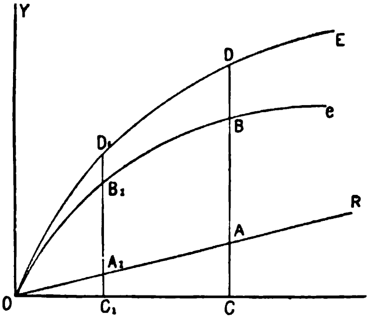


FIG. 37

The wires to be economically used must be continually operated at full load, otherwise at these high pressures on long lines even in the air the charging current required to charge the line at every alternation becomes a very serious loss; this current is the same whether the line is transmitting one horse-power or 1000 horse-power.

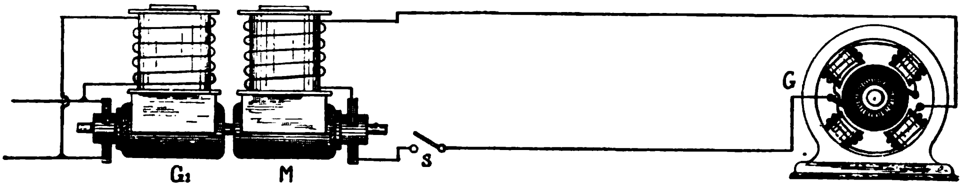


FIG. 38

Such charging currents on long high-pressure lines may amount to several hundreds of horse-power. As a rough idea of the transmission of power a No. 7 copper wire on a three-phase circuit of fifty miles will carry 1300 horse-power with only 10 per cent. loss at 40,000 volts—130 horse-power lost principally in charging current, and in side leakage, and in resistance. This loss would be less of course on small loads, but not much.

Therefore the long-distance schemes must to succeed not only have fully loaded generators, but also fully loaded main-wires to get economy.

The important commercial question is: To what distance can power be transmitted? The relation between distance and voltage is well known. The same weight of copper can transmit with equal efficiency the same power to any distance, provided the voltage is increased directly as the distance is increased. The limiting commercial ratio between voltage and distance is easily found. If the distance be three miles per 1000 volts and the loss 16 per cent., the cost of copper is about £4 per horse-power. The interest on the latter investment is about four shillings per year. A distance in miles equal to three times the number of thousand volts may therefore be covered without an excessive annual charge per horse-power for copper. The limits to the voltage which are practicable depend principally upon the insulator and upon the loss between wires.

Considering the losses to which alternating currents are subject on small and varying loads, and the objections to overhead wires in thickly populated countries, there is great inducement to encourage the improvement in continuous-current high-pressure plant, in fact it is imperative that this should be done to save the large schemes from failure. With continuous current insulation is easier, and the losses in the mains and other things are more proportionate to the load, the power factor is much higher, and there are no charging losses in the wires.

M. Thury deserves much credit for his plucky adherence to high-pressure continuous work, and his installation already referred to in Vol. III. of this work is a model so far as the generating and transmission is concerned, which may be followed with advantage.

In this case the high pressure is obtained by dynamos in series, each giving from 1500 to 2000 volts, and 20,000 volts is used on the line. All the cables are insulated for a pressure of 25,000 volts, and are drawn into vitrified stoneware pipes embedded in the concrete floor.

At Saint Maurice each pole is provided with a set of lightning arresters, consisting of three arm arresters and a Thury type arrester in parallel; this equipment will later be doubled, as it has already been at the receiving station.

The insulation resistance of the line measured at 20,000 volts between the lead and return was found to be 6.66 megohms at 12° C., the day after a rainy day.

Trials have been made of the practicability of utilising the earth as a return in case of need, from which it has been ascertained that the losses depend solely upon the resistance of the terminal electrodes; but these tests have not yet been completed.

At the receiving station, at Pierre de Plan, in Lausanne, there are five series motors in place; five others will be installed as required. Four of these are coupled direct to three-phase alternators working at 3000 volts, for the supply of light and power to the town of Lausanne and its environs; the fifth is coupled to a traction generator of the Thury type. The motors are of the series type, Fig. 39, of 400 horse-power each, taking 150 amperes at 2100 volts, and running at a constant speed of 300 revolutions per minute. They are of the same type as the generators at St. Maurice, the armatures being 550 mm. in length instead of 700, and having a resistance of 0.2 ohm each. The field magnets are in two series-parallels, having a resistance of 0.2 ohm. The speed is maintained constant by the regulator, which shifts the brushes up to 1300 or 1400 volts; beyond this value the regulator varies a resistance in a shunt circuit across the field magnet winding, so as to strengthen the field. The brushes traverse an arc of almost 90 degrees, being opposite the middle of the pole-pieces when the machines are stopped. The variations of speed under normal conditions do not exceed 1 per cent. on either side of the mean. The motors are coupled to three-phase alternators, which are put in parallel with the greatest ease. All the motors have undergone the same tests as the generators. Each motor is provided with a fly-wheel of 3800 kg., and a similar fly-wheel is mounted on the shaft of the alternator coupled to each motor, as shown in Fig. 40.

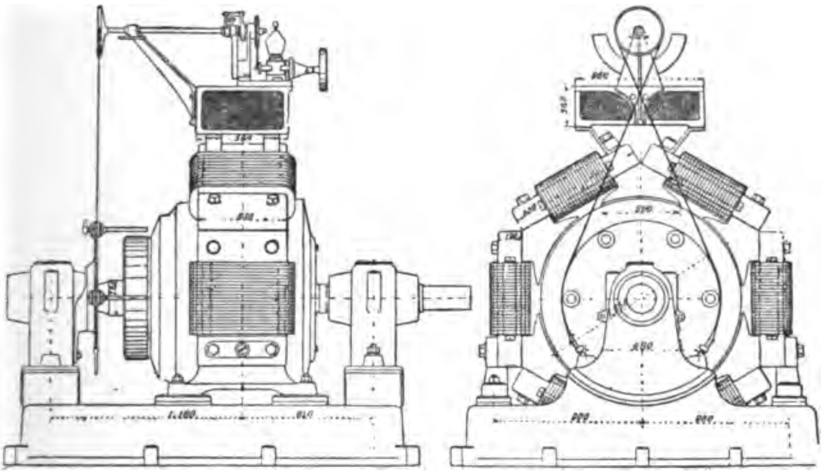


FIG. 39.—Thury's Direct Current Motors

We understand that M. Thury has never had to repair the field magnets of any of his machines, some of which have been running fifteen years, and no commutator has ever been replaced through wear. The upkeep in the series installations, for which M. Thury is noted, is practically nil. Some machines have been running eighteen hours a day for six years with the same carbon brushes!

Fig. 40 represents one of M. Thury's motor-generators complete. The gearing on the top of the continuous-current machine is a mechanical regulator, to adjust the pressure and current and move the brushes. At one time much ingenuity was expended in designing mechanical automatic gear for regulating generators, but now we would depend more upon electrical regulation.

My own scheme for distribution in bulk over large areas would employ continuous currents up to 20,000 volts. The generators would be gas-engines, driving dynamos in series, the armatures in series, and the fields separately excited at 200 volts. Ten armatures, each of 100 horse-power at 2000 volts in series, all driven by one engine, would form each unit generating at the station. It is not necessary to have each armature on a separate shaft. They may be all coupled up in line on one shaft, much as it is shown in Fig. 89, Vol. I., for boosters and balancers, using insulated couplings of course.

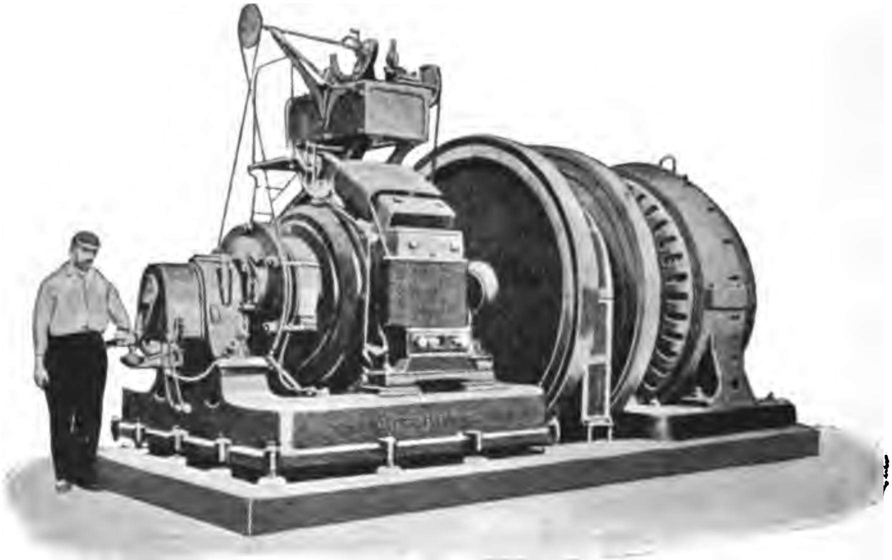


FIG. 40.—Thury's Motor-Generator

The receiving stations would have a special series of motor-generators, with the motor-armatures in series, and the generator-armatures in parallel, all separately excited from the low-pressure bus bars, to which would also be coupled an accumulator, thus forming subsections from which the supply would be led to consumers at lower pressures.

A great deal could be written about these large schemes, but as they are not of interest generally, and only concern a few engineers, we will not go further into the subject in this work.

Having now considered the questions in laying out a generating station, the dynamos are next in order. It has been seen in the foregoing pages that the dynamo is the least important element in the conversion of energy into electricity: the energy of the fuel has been degraded to heat in the first instance, it is then raised to the high grade of mechanical energy by the engine at a loss of from 75 to 90 per cent. The dynamo is then used to translate the high-grade mechanical energy into another high grade of electrical energy. The great losses occur in first allowing the fuel energy to fall to the low grade of heat, and the engine being capable of converting only a small portion of this heat into the high mechanical grade. But given the energy in any high grade, it is possible to convert it into another equally high grade form with little loss; this is the duty of the dynamo.

The dynamo itself is a simple machine forming part of a complex combination of apparatus for obtaining electrical energy from fuel; this is the true definition of a dynamo-electric machine when used in the generation of electrical energy.

As might early have been expected, the dynamo would resolve itself into one or two common types.

For all ordinary purposes the Continental, American, and British leading manufacturers have adopted the multipolar direct coupled dynamo at speeds ranging from 150 to 500 for all sizes but the very smallest with slot armatures and former wound coils. Not long ago efficiency was the cardinal point in the choice of a dynamo by young electrical engineers, and wonderful and fearful were the devices arranged to make the efficiency tests to find out whether it was 94½ or 94 per cent.; money, time, and materials were spent in ascertaining all the values to five places of decimals, with apparatus often not correct beyond the first decimal figure, and by very doubtful methods.

As a matter of fact 2 or 3 per cent. more or less efficiency is a very small matter in practice, if the machine has otherwise what may be called first-class "running qualities," well made mechanically, fixed commutation, cool and sparkless, requiring no skilled attendance, all the little details well thought out and constructed; a running test of five or six hours is all that is necessary; efficiency is of far more importance in small motors wherein it is seldom ever thought of.

So many good makers making the same good dynamos, the engineer can make his choice on the price of the machines, having of course a guarantee as to temperature rise and fixed commutation, and sparklessness under all loads. If the ordinary speeds mentioned are adopted with reciprocating engines, these ordinary standard dynamos are all that can be desired.

If gas-engines are adopted they are also suitable in every way for direct coupling.

If turbines are adopted then higher speeds are desirable and commendable.

For smaller stations such as are to be found connected with factories, mills, and institutions, the same arguments apply as to the larger supplies : that many more of these isolated plants are not in use is wonderful ; the education of the controllers of these concerns is very slow in the direction of new methods and new machinery. As an example within my practice : a large factory of old standing and repute was recently overhauled, taking out old boilers and old engines, to be replaced by more modern plant for driving, without in the least altering the transmission plant, innumerable belts, ropes, pulleys, wheels, and so on; simply new engines and boilers. Of course the new plant showed a very considerable improvement on the old, but it is safe to say that not over 30 per cent. of the power of the new plant was usefully employed. The most wasteful part of the plant was retained. Every care taken to obtain a high-class engine and boiler at great cost ; but without the least concern about wasting 70 per cent. of the power of the splendid new plant.

Suppose the old plant took 4 lbs. of coal per hour per horse-power, and engine indicated 300 horse-power, the consumption would be 1200 lbs. per hour, the new plant consumption 600 lbs. per hour ; in both cases the actual power used is 100 horse-power, 200 lost in transmission ; that would amount to 12 lbs. per horse-power per hour for the old plant, and 6 lbs. for the new per actual horse-power hour of work.

If electrical transmission had been adopted even under the worst of conditions, and with no special adaptations, not more than half the power would have been lost, so that a 200 horse-power engine would have been quite sufficient for the work, reducing the coal to 400 lbs. per hour. And by properly-distributed small motors, throwing out numerous ropes, belts, pulleys, it would have been safe to predict that a 150 horse-power engine would have done all the work of the present 300 horse-power, so far as the actual useful driving of the machines is concerned.

Factory and mill owners must be enlightened on these points, for more economy is to be obtained by adding a dynamo to the engine, and changing the transmission of the power to electric transmission, than by a change of engine, if the existing engine is at all within reasonable economy and modern make.

Manufacturers would do well to have this saving in power looked into. In many cases where the factory has outgrown the engine power and it is labouring disadvantageously overloaded, relief can be given by a judicious change to electric transmission, by a dynamo driven as direct as possible from the engine, and a few motors to cut out some of the longest and worst drives.

An experienced electrical engineer can effect a wonderful economy in works which have been extended from time to time by shafting and belting, and even where steam-engines have been put down for the extensions, electrical transmission will be found better and more economical.

Electricians have themselves to blame in many cases for the obscurity of this matter to the eyes of manufacturers. Even experts and electrical journals talk about "electro-motive power," "electric power," "electric power substituted for steam," while there is no such thing meant. What is to be impressed on the ordinary layman's mind is, not that there is electric power available for him, but that he will save immensely by transmitting his power throughout among the machines to be driven, by electric wires and motors instead of by ropes, belts, and pulleys.

The manufacturer must get power either from his own power plant—steam, gas, or water—or he can buy electricity from some one else who has a power plant; but however he gets his power, it should be strongly impressed that it must be brought right up to the work to be done with as little gearing as possible; therein the saving lies.

Referring to the case just considered, suppose the manufacturer, instead of putting in a new boiler and engine of 300 horse-power, had put in a dynamo-electric machine as a motor, and bought electricity at one penny a unit to work it—such a motor might take 250 units per hour, or 240 if highly efficient—costing £1 per hour to run it at least, he would be worse off than ever, for he would be wasting about 14s. an hour. This shows the fallacy of preaching that electric power is cheaper than steam power, while all the time the preacher means that electrical transmission of power is cheaper and better than mechanical transmission.

The loose language used is a positive detriment to the spread of correct notions. It arises from the idea that electricity is a prime mover in installations, which it at present is certainly not. It is merely the carrier or transmitter of the engine power from the engine to the machine to be driven, through a motor.

The general body of people interested in the use of power may never fully understand the jargon of the electrician, any more than they fully understand the thermo-dynamic science of the steam-engine which accounts for the superior economy of triple expansion and automatic cut-off gearing; but most fairly educated, intelligent people can be shown that an apparently dead copper wire without motion, and yet transmitting maybe 50 horse-power to a machine a couple of hundred yards from the engine, and round a few corners and a floor or two above it, is to be preferred to several lengths of 2½ in. steel shafting, a dozen cast-iron pulleys, and half-a-dozen 8-in. leather belts, many brackets, and hangers, lubricators, guards, &c.

But it is then said you require the motor and dynamo, of course. Well then, the proper way to treat these machines is to consider them as parts of the plant. The dynamo is a part of the engine, added to it as an improvement to enable its power to be delivered to any machine in any part of a factory without shafts, pulleys, belts, ropes, or other mechanical gear; it also enables the engine to provide lighting for the factory. It adds only to the first cost of the steam plant by the price of the dynamo.

The motor is a part of the machine to be driven just the same as is a driving pulley or belt. Now when we add the dynamo cost to the engine and the motor cost to the machines, and deduct the cost of all the mechanical gearing required if no motors or dynamo are used, and also deduct the extra boiler and engine power (for a 100 horse-power engine with dynamo and motors will do the work of a 200 horse-power engine working with mechanical gear transmission), the first cost comes out in most cases about equal, if a proper selection of plant is made. In some cases it comes out a good deal more for the first cost of the electric plant, but in these cases unsuitable machinery and motors have been adopted, and motors used which are far too large for the work, and a dynamo also too large and at too slow a speed. To get this selection properly made it must be done with skill and knowledge, and should be in the control of an engineer entirely independent, one who has no system to work, nor plant to sell, whose whole object is to put in the best plant at the least cost in the factory under consideration. Repeat installations can rarely be carried out, circumstances differ so much. When we come across engineers laying down installation after installation stereotyped, it is safe to assume some of them will be very unsatisfactory.

Now it can be demonstrated that the first cost of equipping a factory electrically is only slightly, if at all, greater than a mechanical outfit. The saving in power ever afterwards is clear gain, and amounts to a large annual sum.

The isolated installation is therefore well worthy of the close consideration of power users, and is of still more importance if a group of manufacturers can combine to erect one common generating plant within short distance from each other, say within a one-mile radius.

The power supplied would not cost much over a halfpenny per unit, very probably less, and a manufacturer presently using an indicated horse-power equal to say 100 with mechanical transmission, would find, if he replaced the transmission by electrical, that 50 horse-power would do the same work. There is a very large field of operation here for electrical engineers, independent of the exclusive-dealing municipal trade.

The isolated plant may be considered further as regards the wiring. The wiring of towns and cities for municipal supply is a subject by itself, and does not concern a large class of engineers. It is simple enough, but we will not enter into it here.

In an isolated plant the engineer has a free hand. That being so, he will select the pressures and methods best suited to the job in hand.

First, then, for small installations of power transmission under 30 horse-power, and with no motor over 5 horse-power required, a plain two-wire 110-volt installation is all that is desired. The maximum power being 30 horse-power, the average will be about 15 in most cases; in letterpress printing-works it may average only 10 horse-power.

For such a small plant steam is out of the question altogether; an oil or gas engine is the best prime mover in such cases. A gas-engine would run at about one penny per horse-power per hour on ordinary town-gas supply, in most places somewhat less than one penny. Messrs. Hornsby claim for their Akroyd oil-engine the production of 1 horse-power for one farthing per hour, using common fuel oil. As this is a remarkably low consumption, I will select this engine for example.

The engine is started in the first instance by heating the vaporiser with a lamp, but after that the heat of the explosions and compression suffices to maintain the temperature, and the engine may be stopped for a few minutes without reheating.

The dynamo for this installation should be the simplest possible. There are so many good ones to choose from that a machine at a fair price can easily be obtained; it should, however, be run on full and varying load for six hours as a test. The dynamo should be made with a third terminal for running without the compound winding for charging accumulators, for the purpose to be presently described.

The switch-board should consist of two panels, one containing a main circuit-breaker, a volt meter and ammeter, the other for the battery circuits charging and discharging, with a charge over switch and a circuit-breaker, as shown in Fig. 41.

As to the motors, the same remarks apply as to the dynamo. There are plenty to select from, all equally good; it is only a matter of price.

Now in such an installation probably 200 lights would be required, and as the power and lights in winter time would both be required at the same hours of the day, another 20 horse-power plant would be required for the lighting alone. And in ordinary factories working from 6.30 A.M. to 5.30 P.M. from March till October, the lighting would be an idle and unproductive plant; it would be far better to employ storage if possible. The lighting hours in the depth of winter would average about five hours a day at most, tapering off to zero both ways. It would be easy to arrange the power plant to charge the accumulators every evening after 5.30, putting in the quantity taken out that day, and the requisite extra quantity to make up for losses. This can be done, as explained in previous volumes, by meter and checked by a recorder. Forty-two cells would be sufficient, giving 80 volts on discharge, and charging at 100 volts, using 80-volt lamps, and 100 volt motors.

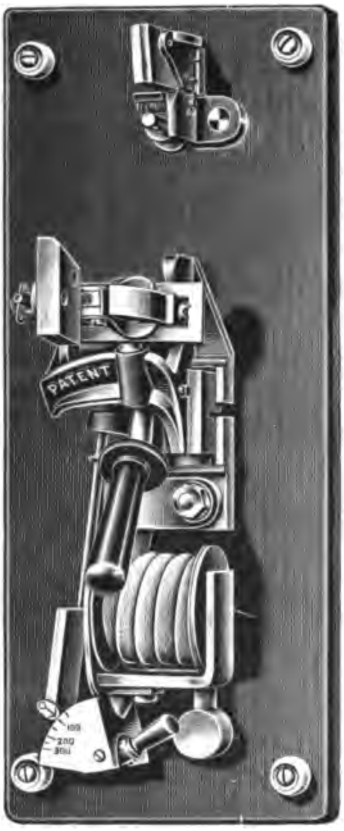


Fig. 41.—Automatic Circuit-Breaker

In this way the one plant would be ample for both light and power, but the question of lighting is not always to be mixed up with the power transmission question. There is only one best method for power transmission, and that is by electricity; but there are many systems of lighting, and in many cases lighting is cheaper and better by other means than electricity generated on the premises, at any rate in all installations the power and the light should be considered entirely apart; electric light has no advantages in many cases over gas-light, even if the cost is the same, while in many cases electric light is much to be preferred, even if at higher cost; gas is good enough in other cases. This lighting question is one for the factory owner to settle; it requires no engineering skill to decide that question. But the question of distributing the power is another matter; the electrical engineer can offer substantial benefits in that direction.

Now, for a larger installation of power plant in a factory, a medium size, say 150 horse-power, or about equal to a mechanical distribution taking 300 indicated horse-power. The system would not comprise any motor over 10 horse-power, the majority being under 3 horse-power, and some about 1 horse-power or less. In such a system the motors should be divided into two classes if there are many over 5 horse-power, and more than four or five over 3 horse-power, all those under 3 horse-power being on 125 volts, and those over 3 horse-power on 250 volts on a three-wire system. We have already, in discussing motors, seen that small motors on high pressures are "dear and nasty," owing to the fine wire windings required.

The best plant in most cases where condensing water was available would be a steam turbine plant of the De Laval type, with two armatures in series to form the third connection between to the three-wire system, a plant shown in Plate III. Where no condensing water is available, a compound vertical quick-revolution engine with a dynamo on each end of the shaft would be perhaps better. In either case, one spare armature would be a safeguard against stoppage. In this case, where ground is available, the power is large enough to consider a gas plant, but the space for the gas-holder and gas-generators is not often to be found.

Another alternative is a pair of oil-engines, with a dynamo on each engine, driven by a thin high-speed belt, at one farthing per horse-power hour. This, considering all things, would be a safe plant in many cases. No chimney or boiler being required, and not much space, renders it a very good alternative in some cases where the power required is no more than that under consideration.

For the larger powers the case is different. Factories requiring larger powers, as a rule, can choose their site to fit the power, while smaller factories in many cases require to choose the power to suit the site. We have already considered the case of larger powers.

In this country continuous-current plants are nearly all similar. Steam plants with quick revolution engines, vertical compound or triple expansion engines coupled to multipolar dynamos, some few of the earlier plants having bipolar dynamos of immense size.

An important question arises as to the use of accumulators in large continuous-current installations. We have just referred to one method of using them in a small work, driven by transmitted power electrically. Their successful use depends on circumstances, like everything else, and these circumstances must be carefully considered.

In small town installations their usefulness is beyond doubt. In these places the summer load is very small for lighting, as can easily be seen by studying the gas consumption for different months. In Scotland, for instance, where Sunday closing and ten o'clock closing of all places of amusement and refreshment exists in small towns, the lighting from Saturday night till Monday night could easily be run from quite a small battery in summer time without any engines or attendance at all, for instance in towns under 30,000 inhabitants. A battery in these places can many times take on the whole load, and thus enable the station to be shut down. Even if they can find room for a tramway in a small town, then the battery is useful in steadying the load, especially if fitted with an automatic booster.

The proper installation, on the whole, for such small towns is a gas plant with accumulators. The gas can be stored ready for immediate use without much expense, and the gasworks may be outside the town on some ground of little value for anything else. The demand in small towns is subject to much greater fluctuations than that in large cities, and even in winter drops to a very small value after ten or eleven o'clock at night, while Saturday night represents a maximum demand. By the aid of the battery and the gas stored ready for emergency, these fluctuations can be met without running a large generating set at small load, and thus the power factor of the plant may be very much better than that of a steam plant.

Despite these obvious facts, small towns are prone to simply follow the example of large cities, with results anything but satisfactory to the municipal ratepayers.

The gas plant in small towns would also give a cheaper cost per unit, so that small industries using small motors might come on as customers for a day load at about one penny per unit, and thus oust the small gas-engines now in use.

In large installations in cities the accumulator is of little value. The demand in these large installations is always of large enough dimensions to keep some dynamos working, and the generating plant must be large enough to cope with the maximum demand at any time.

On the question of isolated generating plants, compared with a supply delivered in bulk, it is interesting to study the figures and facts given in a paper by Mr. Selby-Bigge to the Iron and Steel Institute at Düsseldorf.

The figures could be confirmed by most engineers engaged in isolated installation work, and they show conclusively that distribution of the engine-power in works is a vast improvement over all other methods; and also that the owners can, by laying down a generating plant of their own under an experienced engineer in this line of business, obtain the electricity at a price below any supply yet known from central stations.

These figures are taken from actual examples of everyday working, and are not in any way test figures taken for the purpose. Taking these figures as a basis, it is an easy matter for a works owner, once having ascertained the total horse-power which will be involved in the driving and lighting of the entire works, to see for himself at what expenditure per annum he can run his works upon the new system.

COST OF ELECTRICITY DELIVERED ON SWITCHBOARD.

Test of 139½ *hours, November* 17*th to* 23*rd,* 1901, *Britannia Works.*

Mean current (amperes)	3,464
Mean pressure (volts)	125
Mean power (watts)	433,000
Mean electric horse-power	58,042
Board of Trade units	60,403
Weight of steam per B.T.U.	27.52 lbs.
Weight of coal per B.T.U.	3.04 lbs.

	Cost per B.T.U.	Cost per Week.
Coal, 3.04 lbs. at 11s. 6d. per ton	0.187	£47 4 0
Water, 27.52 lbs. at 3½d. per 1000 gallons	0.00963	2 8 6
Stores	0.00995	2 10 0
Wages	0.06625	16 13 3
Repairs[1]	0.0159	4 0 0
Superintendence	0.01192	3 0 0
Net cost per Bo.T.U.	0.30065d.	£75 15 9
Interest and depreciation on £15,000 at 10 per cent. per annum	0.099d. per unit.	

[1] Includes labour of keeping 134 arc lamps in repair.

COST PER E.H.P. PER HOUR.

Coal, 2.27 lbs. at 11s. 6d. per ton	0.1395
Water, 20.53 lbs. at 3½d. per 1000 gallons	0.00718
Stores	0.0074
Wages	0.0494
Repairs	0.01185
Superintendence	0.0089
	0.22473d.

Mean I.H.P. at 75 per cent. efficiency, 773. Coal per I.H.P.-hr., 1.705 lbs. Water per I.H.P.-hr., 15.4 lbs.

Mr. Selby-Bigge also gives facts regarding a large engine-works, now running on 7½ tons of coal per day, and employing 800 men. This works consist of four distinct yards, all yards are driven from one central station, and in the old method a boiler would have to be placed in each department, or else long lines of wasteful steam-pipe. The cost of production, including interest and depreciation on capital, is 0.46 of a penny per unit.

At a shipyard on the north-east coast, using only 112 H.P., the cost of production of electricity has been found to be only 0.6 of a penny per electrical horse-power per hour, this figure including all charges, interest and depreciation.

At another shipyard on the north-east coast the substitution of electricity for steam driving shows a saving of 43½ per cent. The figures are as follows :—

Cost of Power per £ Wages paid.

Coal and Gas.		*Electricity.*	
May 2, 1893, to April 24, 1894.		April 30, 1900, to April 30, 1901.	
Wages	£64,885	Wages	£126,700
Cost of power	2,337	Cost of power	2,578
= 8.66d. per £ wages paid.		= 4.88d. per £ wages paid.	

Taking the case of another shipyard which was previously driven by gas-engines, the following are the particulars: "We are getting at least 30 per cent. more power out of our machines since we adopted electric transmission of power instead of the gas-engines we used before.

"As far as the cost per Bo.T. unit goes, we have lately had readings taken, and find that last year's works out at about 0.8 of a penny; this is taking into consideration the depreciation on our plant, interest on capital, repairs, and in fact everything which we can possibly put down against this account."

The average output would not exceed 250 to 300 H.P. in this case.

These facts speak for themselves on the question of whether to put down a private generating plant or take it in bulk from a station, coupled with the consideration that in adopting an isolated private plant the engineer can select continuous current or polyphase current, and at any frequency and any pressure most desirable. There can be no question that the advantages of the isolated installation are great, and that unless electricity in bulk can be delivered at one halfpenny per unit, there is small chance of large consumers making use of electricity transmitted over long distances from coal-consuming stations.

The Mond Gas Company with their cheap gas may reach this low figure, especially on the large scale upon which they propose to operate, so far as production goes; but it seems that the other costs are so great in large areas, compared with the cost of fuel, that even if they got the fuel for nothing the price per unit delivered to the consumer must be very high. It is the other costs between the fuel and the consumer which mount up in long distance distribution.

As an example I may quote the proposed charges for energy proposed to be supplied in bulk over a large industrial area by the North-Western Electricity and Power Gas Syndicate, Ltd.

"The maximum specified charges per quarter for energy are to be as follows :—

"A standard charge for service at the rate of 10s. per E.H.P. for the supply of which the company is required to make provision ;

and in addition a charge for current determined by meter after transforming as follows: For the first 5000 units consumed in any quarter at the rate of 3d. per unit; for all consumed between 5000 and 10,000, 2¾d. per unit; between 10,000 and 20,000, 2½d. per unit; between 20,000 and 50,000, 2d. per unit; between 50,000 and 100,000, 1½d. per unit; between 100,000 and 200,000 in any quarter at the rate of 1d. per unit; amounts over 200,000 units consumed in any quarter, at the rate of ¾d. per unit. Or alternatively—

"1. For any quantity not exceeding the equivalent of 100 hours of supply at the maximum power which has been demanded at the rate of 4d. per unit.

"2. For any further quantity exceeding the equivalent of 100, and not exceeding 200 hours of supply at such maximum power at the rate of 2d. per unit.

"3. For any further supply exceeding the equivalent of 200 hours of supply at such maximum power at the rate of 1d. per unit."

Now taking a quarter as 13 weeks of 54 hours each, we arrive at 702 working hours to consume 200,000 units, and this gives $\frac{200,000}{702} = 285$ units per working hour, 285 kw., or about equal to a power given by a 400 I.H.P. engine. It will therefore be necessary to utilise this power all the time before the price falls to .75 pence per unit delivered.

It will be seen from the above that two systems of charging for the supply are proposed—1st, on a fixed charge, plus a rate based on the amount consumed per quarter; 2nd, on the maximum demand system. But this system by maximum demand, while barely tolerable by small electric light consumers, would be intolerable by large power consumers whose demand fluctuates largely. In these large systems a two-rate meter system would be most satisfactory, and would tend to level up the load line, for the power consumers would take their largest demand on the cheap rate and economise on the high rate. The high rate would be quite cheap enough for lighting purposes.

On the first system the consumer, in addition to the 0.75 pence per unit, has to pay ten shillings per E.H.P., for the supply of which the company has to provide. In the case calculated above, 285 kw. would amount to 380 E.H.P. to be provided for this supposed consumer, so that to the 0.75 pence multiplied by 200,000 units, we add as total cost for supply $\frac{380}{2} = £190$, as a standing charge per quarter; toting up as follows:—

200,000 units @ 0.75 pence	£625
Standing charge @ 10s. per E.H.P. . . .	190
	£815

and $\frac{£815}{200,000} = 0.978$ pence, total cost per unit delivered, on the basis that the average demand by this consumer would be 285 kw. per hour, and his total consumpt per quarter not less than 200,000 units. These charges may, however, be reduced in the future.

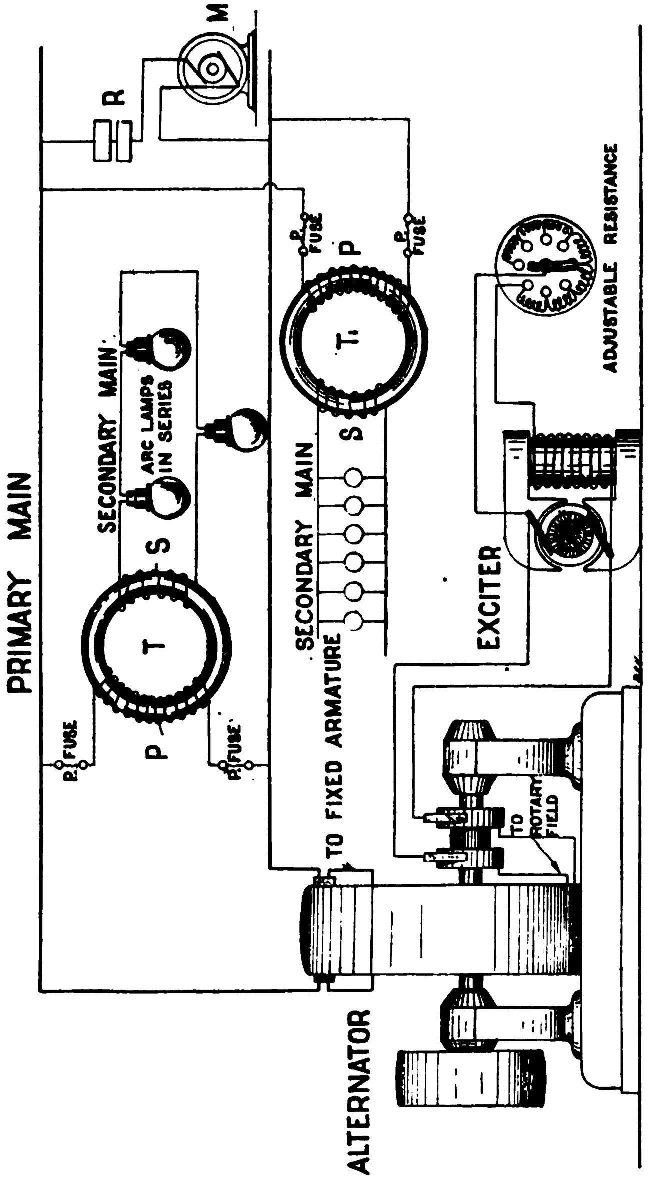


FIG. 42.—Diagram of Alternating Distribution

On a maximum demand system the bill would be far more, for the fluctuations in power demands are very great, and one hour's overload would penalise the consumer to the amount of hundreds of pounds in one quarter.

A two-rate meter system is by far more equitable, and would have the confidence of consumers, while the other two systems are open to suspicion of unfairness.

Fig. 42 is a diagram showing the general arrangement of a distribution system by alternating currents and transformers, T and T_1 being stationary induction coil transformers. In any case where rectified current is required, the electrolytic or gaseous rectifier would be coupled in in series with the device to be supplied with the rectified current, as shown in the figure with a motor at M. R is the rectifier, to be described later on.

The following are reliable figures concerning that latest prime mover.

The latest type of Diesel oil-engine for electric lighting and power purposes is shown in Fig. 43, coupled direct to a dynamo.

Table V. gives the results of tests on a 70 B.H.P. and an 8 B.H.P. engine, made in November 1901, both engines being of the latest type, without piston-rod and crosshead.

TABLE V.

	70 Nominal Brake Horse-power.			
Brake horse-power . . .	87.4	70	55.8	41.2
Mean effective piston pressure, lb. per sq. in. . . .	113	88	79	69
Brake ÷ indicated horse-power .	.80	.81	.72	.65
Fuel consumption, lb. per hour per Indicated horse power .	.33	.33	.31	.31
Fuel consumption, lb. per hour per Brake horse-power .	.42	.41	.43	.47
	8 Nominal Brake Horse-power.			
Brake horse-power . . .	10.0	8.6	4.25	2.9
Mean effective piston pressure, lb. per sq. in. . . .	110	101	63	52
Brake ÷ indicated horse-power .	.77	.72	.57	.46
Fuel consumption, lb. per hour per Indicated horse-power .	.39	.36	.35	.34
Fuel consumption, lb. per hour per Brake horse-power .	.51	.50	.62	.73

The 70 H.P. engine ran at about 160 revolutions per minute, the 8 H.P. at 265 revolutions per minute. The oil used was American petroleum, having a specific gravity of .793 and a calorific value of 18,000 B.Th.U. per lb.

Results of Tests on Diesel Engines

TABLE VI.

Final Results for the Brake Horse-power Trials of the Diesel Oil-Engine, 10th April 1902, at Harrogate.

	Number of Test.			
	I.	II.	III.	IV.
Per cent. of full load	25	50	75	100
Duration in hours	1	1	1	$\frac{2}{3}$
Load on the brake	74.3	138	213	299.6
Spring balance, lb.	3.14	3.36	14	27.8
Effective load, lb.	71.16	134.66	199	271.8
Revolutions per minute . . .	185.4	184.6	183	181.4
Brake horse-power	10.87	20.44	30.07	40.26
Total oil, in lb.	8.95	10.95	14.35	12.30
Total oil per hour	8.95	10.95	14.35	18.45
Oil per brake horse-power hour .	0.823	0.536	0.478	0.459
Cost per brake horse-power hour, with oil at 55s. a ton, pence . . .	0.243	0.158	0.141	0.137
9th May 1902.				
Per cent. of full load	57	98	82	41
Duration in hours	1	1	$\frac{1}{2}$	$\frac{1}{2}$
Load on the brake, lb. . . .	159.4	281.7	246.6	111.3
Spring balance, lb.	4.94	16.1	21.6	3.0
Effective load, lb. . . .	154.4	264.6	225.0	108.3
Revolutions per minute . . .	181.7	182.5	182.7	182.7
Brake horse-power	23.03	39.21	33.1	16.29
Total oil, in lb.	12.25	18.06	7.875	4.75
Total oil per hour	12.67	18.06	15.75	9.5
Oil per brake horse-power hour .	0.55	0.461	0.476	0.583
Indicator Quantities.				
Mean pressure in lb. per sq. in. .	93	117.6	103.2	69.7
Impulses per minute	90.8	91.2	91.3	91.3
Indicated horse-power . . .	42.4	52.27	46.88	31.45
Oil per indicated horse-power hour in lb.	0.301	0.346	0.336	0.302
Cooling water per indicated horse-power in lb.	37.6	33.6	...	...
Inlet temperature in F. degree . .	49.5	49.5	49	49
Outlet temperature	93.5	104.8	93	93
Rise of temperature	44	55.3	44	44

Exhaust Gases Volume Analysis.

	Number of Sample.		
	I.	II.	III.
Carbonic acid gas, per cent. . . .	12.2	12.2	12.4
Oxygen, per cent.	6.2	6.4	6.2
Carbon monoxide, per cent. . . .	0.0	0.0	0.0
Nitrogen, per cent. . . .	81.6	81.4	81.4

Table VI. gives the results of some very exhaustive tests made by Professor Ade Clark, of Yorkshire College, on the Harrogate engine, in April and May last, of which a full report was given in the *Engineer* of 22nd August 1902.

Texas liquid fuel was used, which showed by test a specific gravity of .920 at 65° Fahr., and a calorific value of 19,150 B.Th.U. per lb.

Results of Tests

The total heat accounted for by measurement of heat converted into work and heat carried off in cooling was 96.2 per cent., leaving 3.8 per cent. for radiation. The rise in temperature of the cooling water was 55.3° Fahr.

The heat expenditure came out as follows :—

Indicated power	38.4 per cent.
Cooling water	28.2 „
Exhaust gases	29.6 „
Unaccounted for	3.8 „
	100 „

It must be specially noted that the Harrogate engine is of the older construction with piston-rod, cross-head, &c., and therefore the figures are not so good in some respects as those obtained from the most recent engines.

The exhaust gases analysis is specially interesting, showing that complete combustion was obtained.

It will be observed from the results of the tests given that the consumption per I.H.P. is less at partial load than at full load ; the main cause for this is the increased ratio of expansion. The amount of oil required for lubrication for the Diesel comes out at $\frac{1}{75}$ part of a lb. per B.H.P. hour, which is a good deal less than the quantity used by ordinary oil engines. Forced lubrication is adopted, the oil being fed by a screw plunger, driven by an adjustable pawl and ratchet with wheel motion off the air-pump lever.

Fig. 44 shows a pair of vertical sections of the engine referred to in tests.

It should be mentioned here that equally good results have been obtained with coal-dust and gas, but with the price of oil continually dropping, and liquid fuel becoming more and more easily obtainable in all parts of the world, the use of coal-dust and gas is not likely to be pushed at present. The oil used by the engines running in England is known as Texas liquid fuel, being imported by the Shell Transport and Trading Co., and delivered at most large English ports at 35s. per ton. Freight inland varies from 5s. per ton upwards. The flash-point of this oil is 150° Fahr., its specific gravity .922, and calorific value 19,296 B.Th.U. per lb.

The Diesel Cycle.—The type of engine which has been chiefly developed works on a four-stroke cycle as follows :—

(1) Fresh air is drawn into the cylinder during the downward stroke of the piston.

(2) The air is compressed during the upward stroke to a high pressure, and consequently high temperature.

(3) Fuel is admitted into the cylinder during the first portion of the next downward stroke, combustion taking place as the fuel comes in contact with the highly-heated air. After the fuel is cut off, the

piston continues the rest of the downward stroke under expansion of the gases in the ordinary manner.

(4) The piston returns expelling the contents of the cylinder, thus completing the cycle.

We will now review the considerations which led to the adoption of the above cycle. In round figures, the heat delivered to the cylinder of an ordinary internal-combustion engine is accounted for as follows :—

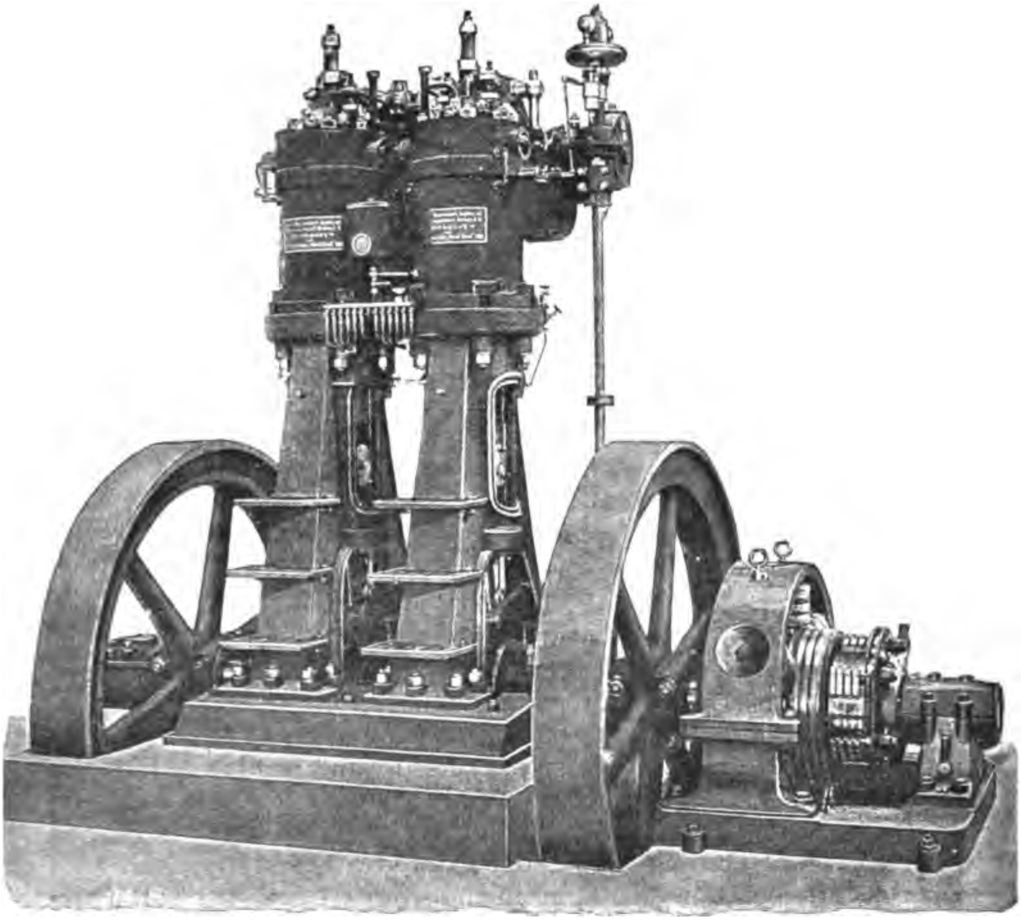


FIG. 43.—Complete View of Diesel Engine Direct Coupled to Dynamo

Heat converted into work	20 per cent
Heat lost by radiation	40 „
Heat lost in exhaust gases	40 „

That is, the thermal efficiency is only 20 per cent., whereas the theoretical maximum with a Carnot cycle may be taken as 72 per cent.

With these facts before him, Mr. Diesel set himself the problem of finding the most economical method of utilising the fuel in an internal-combustion engine. After due consideration he condemned the old system, viz. :—

(1) Gasifying of the combustible.
(2) Mixing same with air.
(3) Compressing the mixture up to from 3 to 5 atmospheres, and igniting it by a hot tube or other usual means, as wrong throughout.

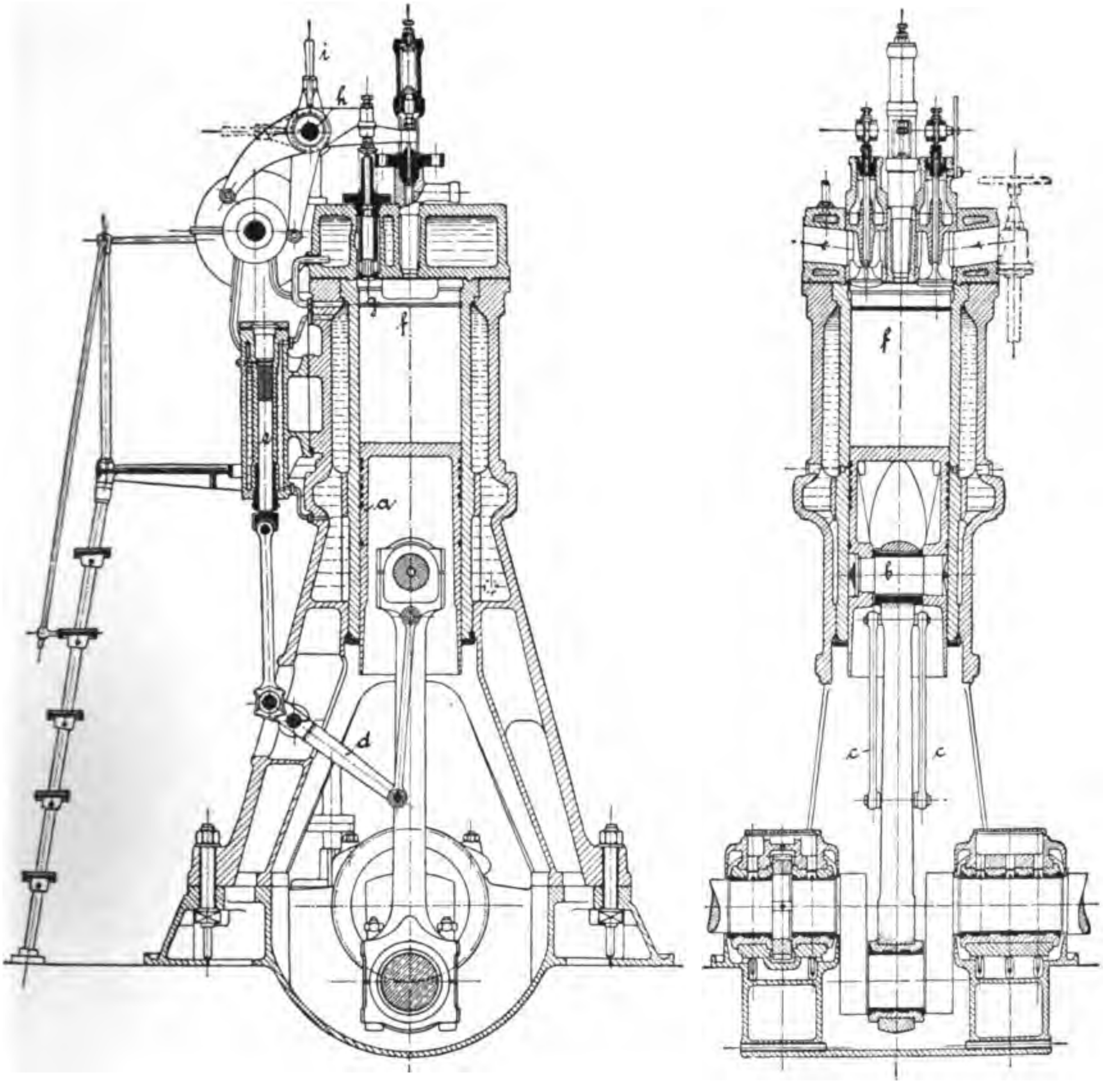


Fig. 44.—Two Sectional Views of Diesel Engine

His great idea was to produce an engine where all the heat was converted into external work, as this would give a maximum heat economy. For some time experiments were made with vapours not easily condensable, and some engines were tried with superheated ammonia vapours. Finally he was led to believe he could best solve the problem by the use of air, and accordingly laid down the following three conditions for the working of a rational heat engine :—

(1) The temperature of combustion must not be produced by and during combustion, but independently of it, and before its commencement, by the compression of pure air.

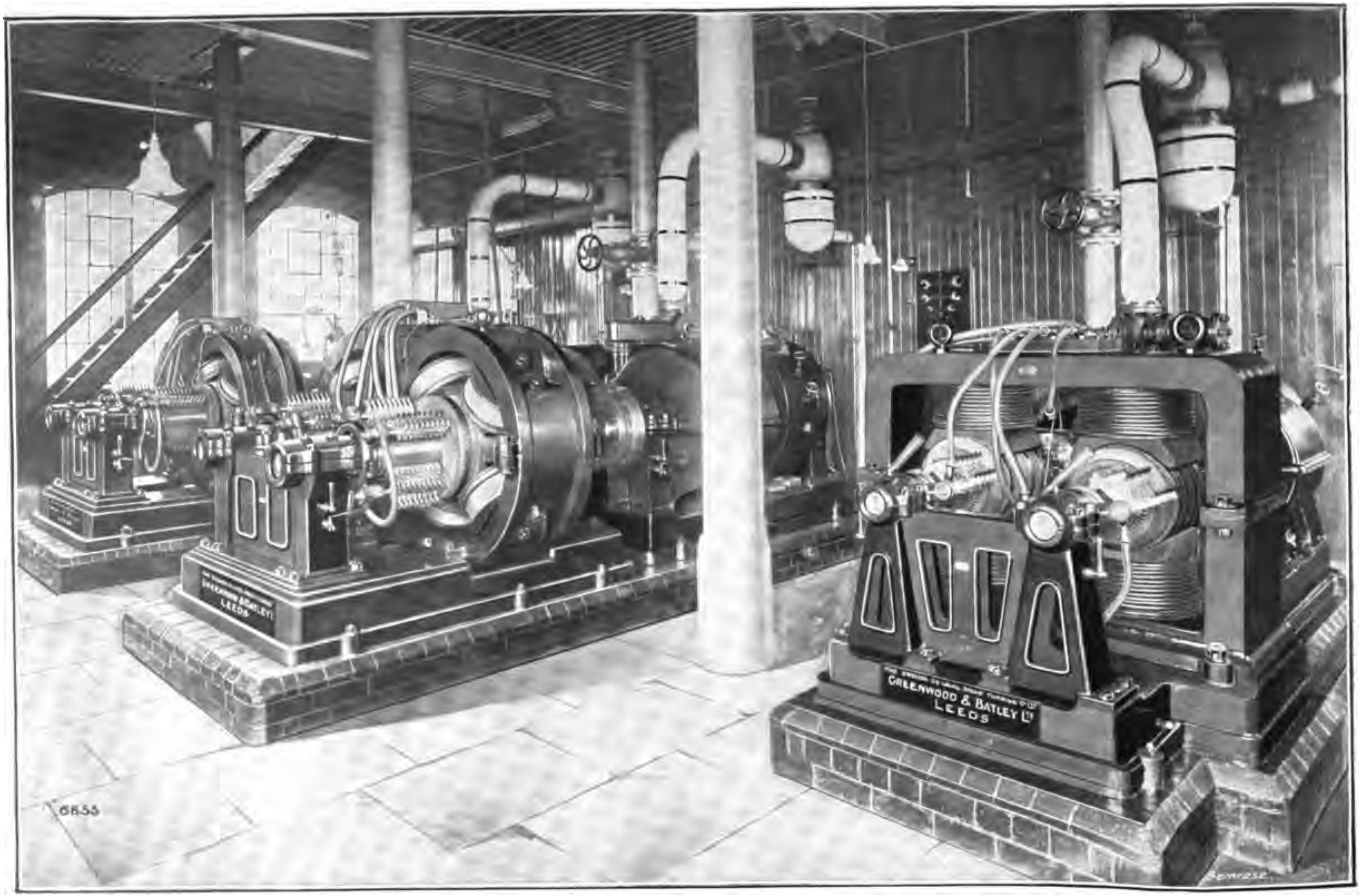
(2) The combustible must be introduced gradually into the air thus brought up to the combustion temperature by compression in such a manner that, as heat is produced, it is entirely absorbed by expansion of the gases, so that no internal work (as a rise of temperature would indicate) is produced, but only external mechanical work. If this condition were realised in practice there would be no radiation loss, and no cooling-jacket would be required.

(3) A considerable surplus of air should be present beyond that theoretically required for complete combustion.

There are four leading features of the Diesel that distinguish it from all other oil and gas engines. The first of these is the attainment of the temperature necessary for ignition by mechanical compression alone, so that all injected flame, or incandescent tube, or electric spark, or other extraneous igniting devices, is abolished. The second is the injection of the fuel only after compression has been completed, and only during the first part of the working stroke, the compression in the working cylinder being that of air alone. Thus no explosive mixture exists in the cylinder before the beginning of the working stroke, and no premature ignition is ever possible. The third distinctive feature is that the fuel is injected gradually into the highly-heated air, each drop of the spray burning immediately and quietly, so that no explosion takes place, while the period of injection and the quantity injected are delicately regulated by the governor in accordance with the demand for power. Thus, fourthly, the governance is effected within the four-stroke cyclic period of thermo-dynamic action, and every such period has its working stroke. Gas and other oil engines are governed by the total cut out of the fuel injection during one or several such periods. Thus, with equal fly-wheel power, the running of the Diesel is much steadier, and the records given below show that its speed-uniformity coefficient is such as makes it very suitable for direct coupling to electric dynamos.

Another important point in installations is the question of transforming the pressures and the currents. The ordinary induction coil transformer can be used with efficiency for step-up and step-down of pressure, but no very satisfactory transformer of current exists to change from A.C. to C.C.

The rotary converter is an admirable machine in its way, but



DE LAVAL STEAM TURBINE GENERATING STATION

to a consumer taking high-pressure alternating current in bulk for use in transmitting power in a works, it is a costly machine. It is, however, the only machine hitherto used, with the exception of a motor generator, which is still more costly and less efficient.

Any attempts at simpler methods and machines have been failures on anything but comparatively small installations, but progress is being made, and as we are now considering the alternating system briefly, a reference to the rectifier system of transforming currents is necessary in more detail than in previous volumes.

There are now three classes of rectifiers known :—

(1) Mechanical rectifiers consisting of a commutator driven by a synchronous motor, as in the Ferranti machine and others.

(2) The liquid electrolytic rectifier, with iron and aluminium electrodes.

(3) The gaseous electrolytic rectifier in mercury vapour, with iron and mercury electrodes.

We shall refer to the last type first.

In Vol. I. of this work the Hewitt mercury vapour lamp was referred to as a novelty; since then it has been discovered that the lamp acts in the same way as the electrolytic rectifier, also referred to in Vols. I. and II. The following description from the *Electrical Review* of London will be interesting at this point in the discussion of installations as a whole.

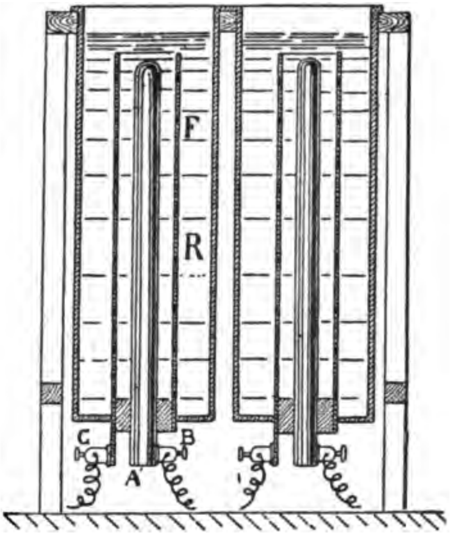


FIG. 45.—Nodon's Electric Valve

Alternating current is of so little use to consumers, that its conversion into continuous current has been a constant study by electricians. The Ferranti rectifier, the electrolytic rectifier, and the rotary converters have been brought out as solutions of the problem. They have met with some applications, but they do not entirely meet the requirements, the last named being a very clumsy and expensive machine for the purpose.

The Ferranti rectifier is good enough for a series of arc lamps, to supply them with a unidirectional current intermittent.

The liquid electrolytic rectifier is more generally useful, and a practical form of it has now been brought out, which may be of considerable value on alternating circuits, under the name of Nodon's electric valve. The apparatus consists of :—

(1) An iron tube F, perforated and closed at its lower portion

by an insulating plug; this tube is provided with a terminal C (see Fig. 45).

(2) A cylinder A, formed of an alloy of zinc and aluminium. This cylinder passes through the plug and is concentric with the tube F; it is provided with a terminal B. The whole is introduced into a cylindrical vessel R, containing a saturated solution of phosphate of ammonium.

The electrolytic actions which take place are as follows: When the current passes in the positive direction from A to F there is instantly formed a film of phosphate of aluminium and of zinc, of alumina and of oxide of zinc at the surface of A. This film presenting an enormous resistance opposes the passage of the current.

On the other hand, if the current passes in the positive direction from F to A (or negative direction from A to F), reduction of the film takes place and the current flows freely.

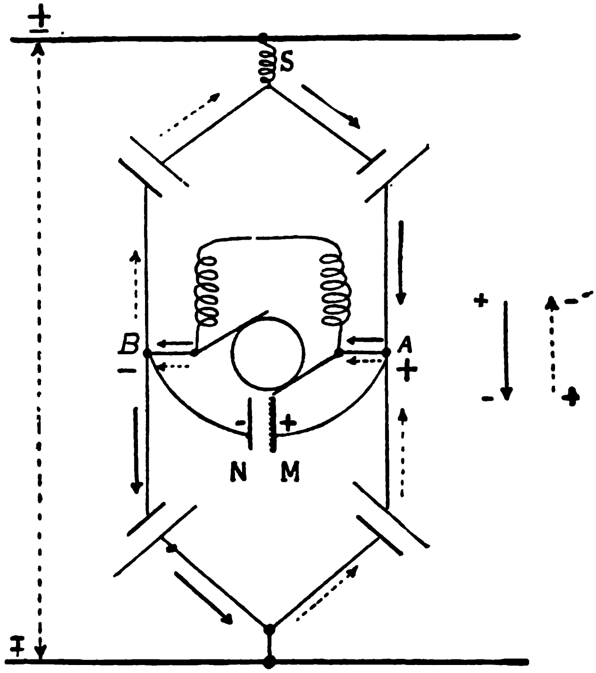


FIG. 46.—Nodon's Rectifier

If now we group four cells according to the Leo Gratz method, it is obvious that owing to the reactions indicated above, the two semi-phases ⇅ of the alternating current will be in the same direction ↓ ↓ in a utilisation circuit (motor, accumulator, arc lamp, &c.) (Fig. 46).

If it is only desired to utilise one semi-phase, the valve is reduced to its simple form; it comprises only one cell. In this form the appliance may act as an interrupter.

For polyphase currents, the rectifier comprises as many times two cells as there are wires in the distribution in order to obtain a single rectified circuit.

The cells should stand a tension varying from 50 to 140 volts; a valve will therefore rectify an alternating current, the E.M.F. of which does not exceed 140 volts.

Adjustments.—For electric valves of small capacity, up to 4 kilowatts, the difference of potential may be readily regulated at the terminals of the utilisation circuit with a self-induction coil or with a resistance arranged as indicated above.

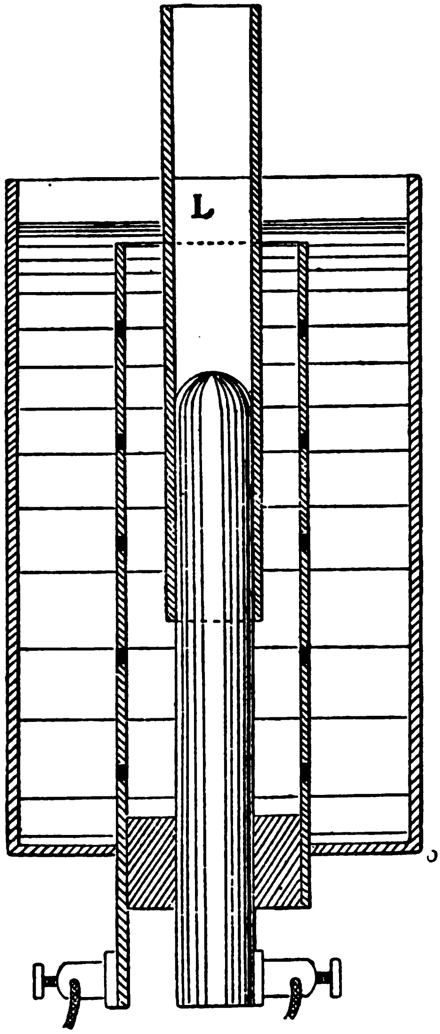


Fig. 47.—Nodon's Rectifier

It is unnecessary to insist upon the enormous advantages, which will be well known to all electricians, of the employment of a self-induction coil for regulating a current instead of a rheostat.

The employment of the valve permits of regulating the continuous current with a self-induction coil.

For valves of a capacity above 4 kilowatts, regulation may also be effected with a self-induction coil or with a rheostat or with insulating sleeves L placed upon the aluminium-zinc cylinders (Fig. 47). This arrangement of insulating sleeves permits of obtaining always the same efficiency from the apparatus. There is nothing similar with rotary machines.

Thus, assuming a commutator or a motor-generator group taking 1000 watts when running light; considering that 70 to 80 per cent. efficiency is obtained with a full load, it is obvious that this efficiency becomes terribly poor when only 500 watts continuous current are utilised.

From this point of view also the electrolytic rectifier presents great superiority as compared with other current rectifiers, as it operates continuously, whatever may be the output required, with an efficiency of 75 per cent. as explained above. These considerations might be developed so as to show easily that the best hitherto known current rectifiers having a high efficiency with a full load frequently have an exceedingly poor average efficiency.

The adjustment of the sleeves for obtaining a predetermined output may be made either automatically or by hand.

Efficiency.—The measurement of the efficiency of alternating current and of undulatory current is obtainable with the greatest exactitude by means of the wattmeter.

It has been found to be from 75 to 80 per cent. with current density not exceeding 5 amperes per square decimetre of active surface of aluminium, and the temperature not rising more than 50° C.

Cooling devices have been adopted in order to maintain a low temperature, such as cold air blown by fans against the cells.

This rectifier is of great interest and usefulness in alternating circuit for motors and arc lamps, electrolytic work, and other uses for continuous currents.

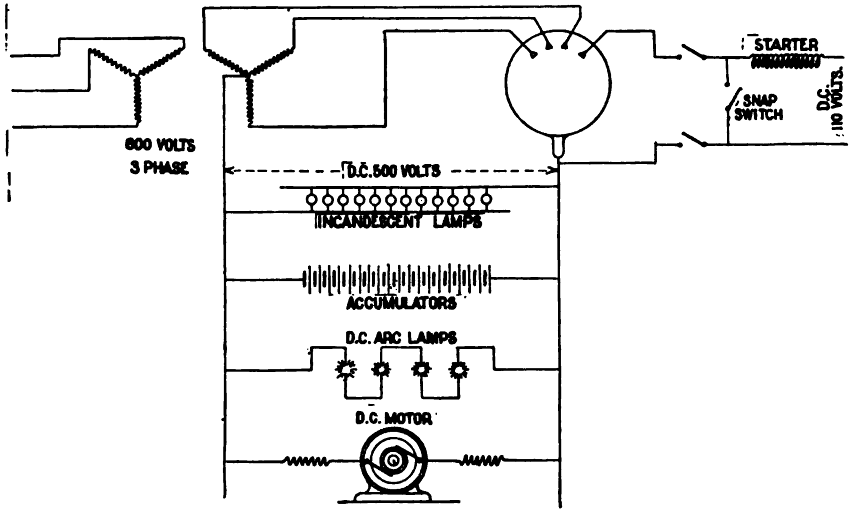


FIG. 48.—Hewitt Rectifier

It is a cheap apparatus of strong construction, inexpensive to maintain, readily dismountable and transportable, not liable to short circuiting, and finally it does not require the repairs frequently necessary in the case of coils constructed with copper wire.

The discovery of the gaseous electrolytic rectifier by Hewitt adds another step to the conversion of S.P.C. and P.C. to C.C. currents. The use of these apparatus must of course result in loss of efficiency, still their simplicity counteracts that loss considerably.

The Hewitt rectifier and interrupter are developments of the experiments with the mercury vapour lamp, and is at present in an experimental form. Their operation depends upon the fact that the current can flow *in one direction only*, through the mercury vapour, so that, in the case of an alternating current, half the alternations are cut off, leaving only those in which the mercury acts as cathode, as in the aluminium electrolytic rectifier. Thus from single-phase current an intermittent direct current is produced, and from polyphase current an almost uniform direct current, by means described below. There is a constant drop of 14 volts in the apparatus, and as it can be used for all pressures from 100 to 1000 volts, the efficiency for the higher voltages is very high—98.6 per cent. at 1000 volts. Currents up to 100 amperes can already be dealt with, and any number of converters can be operated in parallel.

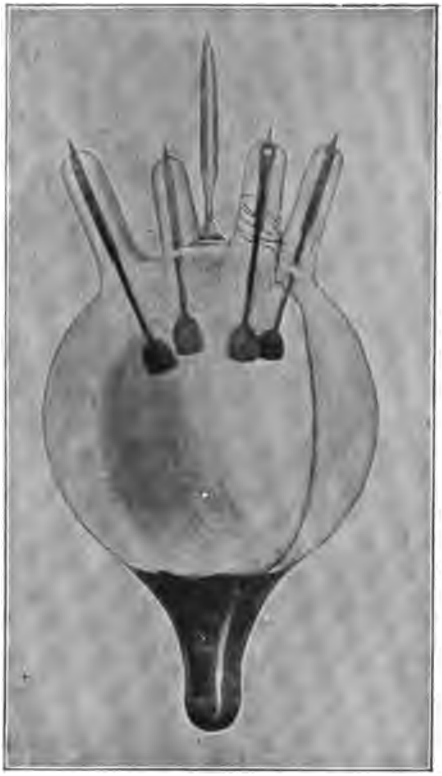


FIG. 49.—Hewitt Rectifier

The diagram (Fig. 48) shows the arrangement of the connections with polyphase currents. After transmission at high pressure, if need be, the current is transformed down to a voltage not much in excess of the direct current voltage required; the transformers are connected starwise, and leads from the three outer terminals are taken to three of the anodes shown in the bulb of the converter (Fig. 49). The pool of mercury forming the cathode at the base of the bulb is connected with one of the direct current bus-bars, the other of which is joined to the neutral point of the star. The fourth anode shown is used for starting the converter by means of a direct current; once started, the action is maintained, each of the three-phase anodes coming into operation in cyclic order, so that the flow of current in the direct current circuit not only never ceases, but is subject to but little fluctuation. The apparatus has been used for converting three-phase to direct current, supplying glow lamps and a direct current motor; the rectified current can be used for charging accumulators and for electrolysis, C.C. arc lighting, &c., and it is thought that the apparatus will be especially useful in place of rotary converters for electric railway working, thus abolishing moving machinery of every kind from the sub-stations, and diminishing the need of attendance. The alternating current in a traction system may also be led into the cars at high pressure, Hewitt converters being carried on the cars to convert to C.C. for the motors.

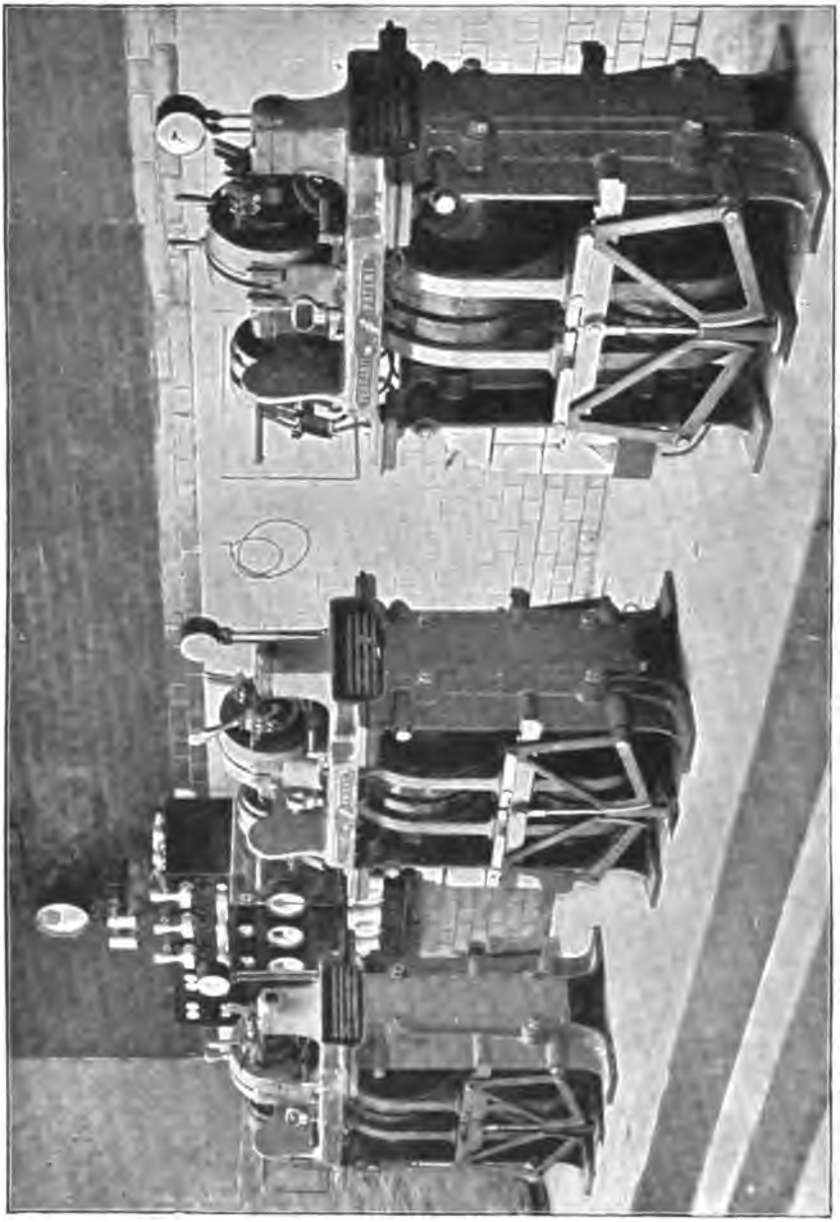


FIG. 50.—Ferranti Rectifier

Although the apparatus is as yet somewhat crude, its possibilities are obviously great, and its evolution to a more perfect type will be rapid in the hands of a powerful company.

The Hewitt lamp, it may be here mentioned, has been brought to a practical success for uses wherein the colour of the monochromatic light which it gives is not objectionable.

We have already described the Ferranti rectifier in Vol. II., which machine has been largely used in alternating current installations for arc lamp circuits, giving a unidirectional current which forms a proper crater on the top carbons, thus throwing the light downwards. A complete installation of three rectifiers for this purpose is here shown (Fig. 50). The rotary convertor can also be considered as a rectifier, but it is, properly speaking, a dynamotor.

Table A., on next page, gives the weights of copper required for the various systems of electrical distribution of power, as given by Mr. H. A. Earle in a paper at Manchester. It shows the relative weights of copper required to give the same loss in the mains when the same power has to be transmitted over the same distance by C.C., S.P.C., or P.C. currents.

Column 1 gives the virtual volts between any two wires when lamps of same pressure, 200 volts, are employed on each system. But as maximum pressure of an alternating current is $\sqrt{2}$ times the virtual pressure, the maximum is shown in column 2.

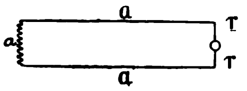
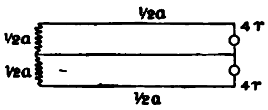
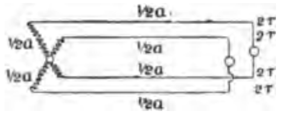
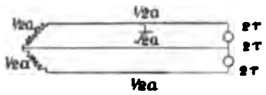
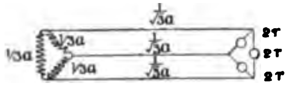
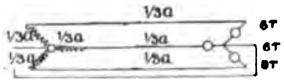
For example, to use the table take 100 K.W. transmitted 10 miles at 1000 volts pressure by a three-phase mesh transmission. In a continuous current system the loss in pressure would be 100 volts at 10 per cent., and 100 amperes would be the current required to give 100 K.W. at 1000 volts; the resistance of the line would then be calculated from $R = \frac{E}{C}$; in this case, $R = \frac{1000}{100} = 10$ ohm, so that a cable of this resistance is required. A reference to a wire table will find the sectional area of conductor to give this, $R = 0.085$ square inches, weighing, total, 17,220 lbs. Now referring to Table A., a three-phase mesh takes only 75 per cent. of the copper required by C.C. current, hence $17{,}220 \times 0.75 = 12900$ lbs., and cable sections will be half, for only half the current, 50 amperes, passes in any one wire, hence, $\frac{0.085}{2} = 0.425$ square inches, and so with other cases. It will be noticed that the three-wire C.C. and three-phase P.C. systems are about equal in weight of wires required. The three-wire continuous current system is, however, really working under this comparison as a two-wire system of 2000 volts.

Other installations may be considered besides those set up for electric light and power transmission. We have often to meet the demands of special cases, such as in mining operations, electrolytic and electro-mechanical processes, and these require much careful treatment by the installation engineer. These will be considered in more detail in Chapter III.

The full-plate frontispiece illustration of the British De Laval Com-

TABLE A.

EQUAL PRESSURE ON LAMPS—EQUAL POWER TRANSMITTED—EQUAL LOSS ON LINE.

System.	Diagram of System. ∿∿∿ REPRESENTS DYNAMO WINDINGS -○- „ LAMPS 200 VOLTS	Virtual Volts between any two Wires $=V$.	Maximum Voltage.	Current in Outers for equal total Power $=200a$.	Resistance of each Outer for equal total Loss $=2a^2r$.	Weight of each Outer. No current in Centre Wire.	Weight of Centre Wire taken as $\frac{1}{4}$ of each Outer.	Total Copper for equal Lamp Pressure Power and Loss.	Weight of Copper C.C. = 100.
Continuous Current 2 Wires		200	200	a	r	1	...	2	100
Continuous Current 3 Wires		400	400	$\frac{1}{2}a$	$4r$	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{9}{16}$	28
2-Phase 4 Wires		200	$V\sqrt{2}$ 283	$\frac{1}{2}a$	$2r$	$\frac{1}{2}$	...	2	100
2-Phase 3 Wires	 ½a ½a $\frac{1}{\sqrt{2}}a$ ½a ½a 2T 2T 2T	$200\sqrt{2}$ 283	$V\sqrt{2}$ 400	$\frac{1}{2}a$	$2r$	$\frac{1}{2}$	$\frac{1}{2}$ Same as Outer	$1\frac{1}{2}$	75
3-Phase Mesh	 $\frac{1}{\sqrt{3}}a$ $\frac{1}{\sqrt{3}}a$ $\frac{1}{\sqrt{3}}a$ ⅓a ⅓a ⅓a 2T 2T 2T	200	$V\sqrt{2}$ 283	$\frac{1}{\sqrt{3}}a$	$2r$	$\frac{1}{2}$	...	$1\frac{1}{2}$	75
3-Phase Star		$200\sqrt{3}$ 346	$V\sqrt{2}$ 490	$\frac{1}{3}a$	$6r$	$\frac{1}{6}$	$\frac{1}{24}$	$\frac{13}{24}$	27

pany's turbine manufactory works in Leeds is an excellent example of the electrical distribution of power as it ought to be in factories. Each machine has its own motor, in fact some of these machines have three motors. There is not a shaft, belt, or pulley to be seen, machines are placed on the floor where most convenient, and a wire led in to the motor. It may be said that such fine subdivision of the power leads to the use of small motors—motors too small to obtain high efficiency in them. That may be the case in some instances where the working pressure is too high, in which case small motors are a difficulty, but in the case of a factory having its own installation, there is no need for high pressure above 110 volts. But even if the efficiency of small motors should not exceed 75 per cent. (a very low estimate for motors under 3 horse-power), and if a 15 or 20 horse-power motor should only reach 90 per cent. efficiency, the difference of fifteen per cent. in favour of the large motor must be reduced by the power required to drive shafting and belting to transmit its power, and also by the constant loss due to the large motor and its gearing running on all the time, whereas the small motor is cut off every time the machine stops. However superior in efficiency the large motor may be, the final result is in favour of the one machine one motor principle.

In this example the machines are made with motors forming part of the machine design : they are the products of Messrs. Greenwood & Batley, of Leeds, who have in their own shops adopted the same system of transmission.

As to polyphase installations these have a limited application in electrical transmission wherein the motors run at constant speed, and are not required to be stopped and started often, and at short intervals. They will be referred to in discussing circumstances under which they may be preferable.

CHAPTER III

HEAT AND ELECTRICITY INSTALLATION

Now we come to consider the production and utilisation of heat derived from electrical energy. The glow-lamp is the most familiar example of electricity running down to heat. Every conductor of electricity offers some resistance to the current of electricity, and this resistance converts the electrical energy into heat; and the amount of heat produced is always proportional to C^2, R, t; t being the time during which the current C flows, and R the ohmic resistance of the circuit.

The quantity unit of heat is the joule, equal to 10^7 ergs, and is the amount of heat generated in a conductor in one second by a current of one ampere in a resistance of one ohm.

The watt is a rate of working, and is 10^7 ergs per second.

A pound of water takes 1058 joules to heat it up 1° Fahr. This is the British thermal unit, the conditions being at atmospheric pressure, and the temperature from 50° to 51° Fahr.

For scientific purposes the gramme degree Centigrade is used at temperature from 0° to 1°, and is the amount of heat required to raise one gramme of water 1° C.; it is equal to 4.2 joules. This is called the "small calorie"; the "large calorie" is 1000 times more in value than the gramme degree, and is =4200 joules.

To find the heat developed by electrical energy in a circuit we can calculate either by C^2R or $E \times C$; E being P.D. between the points to be calculated as the circuit, and C the current, or by $\frac{E^2}{R}$.

For instance, an arc light has a P.D. of 36 volts, and a current of 10 amperes passing = 360 watts, which, divided by 4.2, at once gives the heat generated in the arc per second—

$$\frac{360}{4.2} = 85.72 \text{ joules.}$$

A wire has a resistance of 125 ohms, and the P.D. between its ends 110 volts. Find the heat generated in the wire per second. Here R and E are given, so we use the third formulæ, $\frac{E^2}{R} = \frac{110^2}{125} = 96.8$, and $\frac{96.8}{4.2} = 23$ units.

If we find the heat developed in a second, and suppose it does not escape, the quantity will, of course, accumulate in proportion to the time the current flows, so that it is easy to calculate the heat produced in any given time; and if we know the specific heat of the material the resistance is composed of, and its mass or weight, we can find the rise in temperature in a given time. For instance: A current of 0.75 amperes, flowing 300 seconds through a metal wire of 0.45 resistance ohms, and weighing 20.25 grammes, and having a specific heat of 0.0332, what would be the rise of temperature? By previous examples, we would find the heat per second $\frac{C^2R \times 5 \times 60}{4.2}$, equal to 18.08 units. Now the gramme weight multiplied by the specific heat gives the quantity of heat required to raise the substance one degree, and the temperature X will be found by $X = \frac{18.08}{20.25 \times 0.0332} = 26.89°$ C.

It will thus be seen that the calculations for heating effects are simple in assumed cases, but in practice we have the lost heat by radiation and conduction, which introduces unknown quantities, and consequently we have, as a rule, to employ more energy to obtain a given temperature in a given time than these calculations show.

In Fig. 201, Vol. I., of electrical installations, an electric smelting furnace was shown for making aluminium. We now go further into the subject. There are two methods for heating by electricity, the arc and the resistance methods, as calculated in the foregoing examples.

From an economical point of view, electricity produced by engines and dynamos from fuel is a very costly commodity from which to produce heat, for the simple reason that to produce ten units of electrical energy from heat requires the expenditure of over a hundred units of heat; that is to say, to get electricity enough to give ten pound degrees of heat we have to expend a hundred pound degrees of heat in its production. At first glance it would seem that, therefore, the production of heat by electrical energy would be so costly that it could not become a useful or industrial process, and that is true, with two exceptions.

First, In cases where temperatures of a high degree are necessary, and which cannot be attained by any other means.

Secondly, Where heat is required in a place or position where no other source can reach it.

Some substances cannot be separated from compounds, and some others cannot be combined under temperatures of 2000° C. and over. Now, fuel-fed furnaces cannot reach such high temperatures; the oxyhydrogen furnace which melts platinum, reaches the highest temperature, about 1800° C., using those expensive fuels, oxygen and hydrogen.

The filament of a glow-lamp is a case where heat is produced in a place where no other source could reach it, in a glass bulb and a vacuum.

Electric Furnaces

We are not so much concerned in the products of the furnaces as in their construction and operation, but a reference may be made to the products from the paper read by Mr. B. Blount at the I.E.E. of Manchester, a paper which should be well studied by those interested in high-temperature chemistry; the following are useful products mentioned—

Calcium carbide and silicon carbide (carborundum) are already commercial products.

Alumina is one of those oxides which fuse and volatilise in the electric furnace; on cooling it crystallises as corundum, or, if a trace of chromium is present, as ruby. The case of carbon and its conversion to the octahedral form (the diamond) is too trite for repetition, but the inventor who succeeds in preparing masses of this very hard substance in a determined shape is certain of reward.

A substance which may sooner be made in quantity and put into use is fused silica. Prof. Boys first demonstrated the great possibilities of this material. Mr. Shenstone has shown that quartz fused before the oxyhydrogen blowpipe is in all ways superior to glass as a transparent and refractory material for the construction of apparatus. At present, tanks of glass of fair size can be cast in spite of the brittleness due to its internal tensions. With quartz fused by the ton, and similarly cast, it should be possible to prepare great vessels indifferent to sudden changes of temperature and practically permanent under the most severe conditions. Investigations in this direction are being prosecuted by Mr. R. S. Hutton, who has achieved some remarkable results.

Of useful substances, graphite may be mentioned. Natural graphite is a gritty and inferior material. A hard cutting siliceous ash will make graphite useless as a lubricant, and the merit of some of the brands esteemed for this purpose no doubt rests on their mineral contents chancing to be soft or even lubricative. But with artificial graphite this good property could be procured by design instead of accident. All forms of carbon, crystalline or amorphous, are converted into graphite at a temperature sufficiently high. It follows that artificial graphite may be manufactured by heating directly any kind of carbon sensibly free from mineral matter. A method, differing from this in principle, consists in dissolving carbon in a fused metal until it is saturated at a high temperature; on cooling, a portion of the carbon is thrown out of solution as graphite.

Crystallisation from a supersaturated solution of carbon in a metal, or its carbide, may be supplemented by providing the metal with some other substance with which to unite, and thus displacing the carbon. All engineers know that grey pig run down in a cupola becomes harder, but not every one may be aware that this is due to selective oxidation, which tends to eliminate silicon, and thus to allow the recombination of the iron with carbon previously displaced by that silicon as graphite. Conversely, if silicon is added to iron saturated with carbon a portion of the carbon will be displaced and appear as graphite. There are, therefore, three methods for the manufacture of graphite by means of the electric furnace.

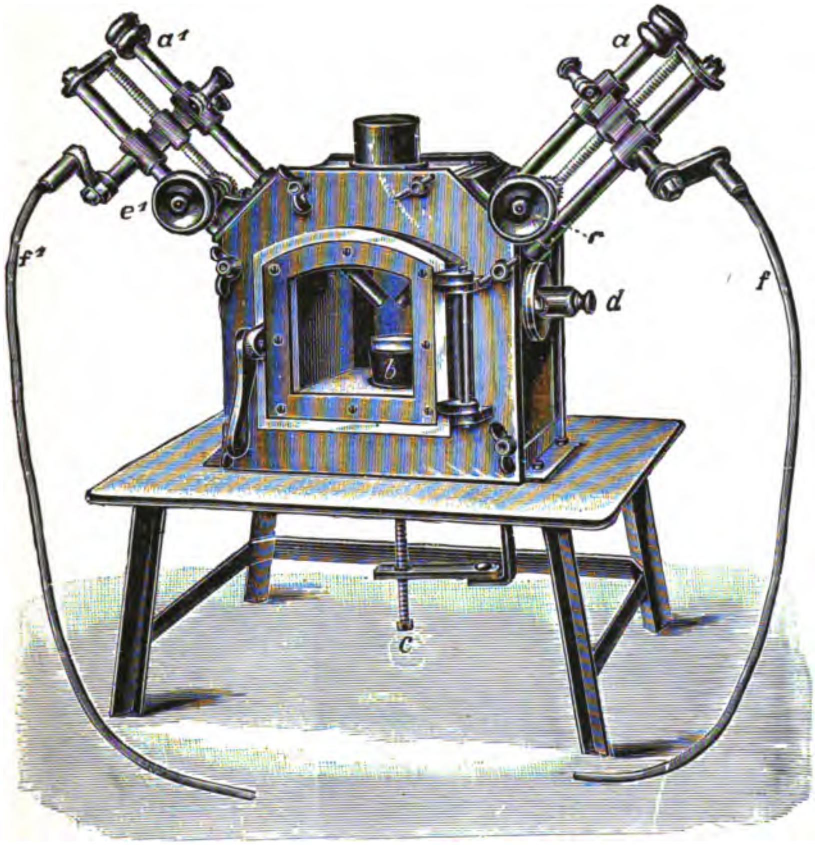


FIG. 51.—Moisan Furnace

Acheson in his U.S.A. Patent No. 568,323 claims broadly the manufacture of graphite by the decomposition of a carbide, a claim which clearly is untenable because the decomposition of a carbide and the production of graphite thereby have been known for many years. Whether Acheson's methods are followed or not, it is probable enough that artificial graphite will eventually displace the natural material. Graphitised carbons are also manufactured by heating ordinary carbons electrically to a temperature high enough to convert them partially into graphite.

A number of refractory metals, such as chromium, tungsten, and molybdenum can be readily prepared in the electric furnace; one at least—*e.g.* chromium.

M. Moissan of Paris first made use of the arc heater, and in fact discovered nearly all the products of high temperature actions and reactions; his furnace is shown on a large scale in Fig. 51 as supplied by Messrs. O. Berend & Co. The arc can be perfectly controlled by the hand wheels, and the whole operation closely observed.

This original chemist has done more to put our knowledge of reactions at high temperatures on a sound footing than any of his predecessors or contemporaries. Moissan has succeeded in fusing, volatilising, and crystallising such refractory materials as lime, magnesia, platinum, silica, zirconia, and carbon. He has studied the allotropy of carbon, and incidentally produced the diamond; he has prepared a whole series of novel carbides, borides, and silicides, and on the basis of his experiments he has advanced a new and sagacious theory of the origin of petroleum.

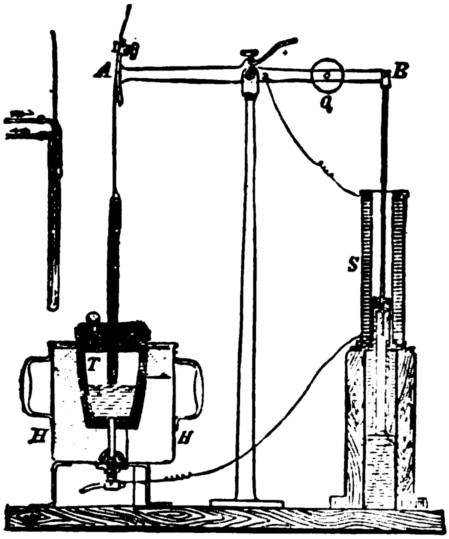


FIG. 52.—Siemens Furnace

The first furnace made on the automatic regulation principle of the arc lamp was made by Siemens over twenty years ago; it is shown in Fig. 52. The arc is maintained of proper length by the solenoid and plunger balance on the beam by the negative electrode which enters the crucible.

Siemens laid down those principles on which the successful operation of the arc furnace depends. He proceeds successfully to experiment, and states: "In working with the modified medium-sized dynamo machine, capable of producing 36 webers of current with an expenditure of 4 horse-power, and which, if used for illuminating purposes produces a light equal to 6000 candles, I find that a crucible of about 20 centimetres in depth immersed in a non-conductive material is raised up to a white heat in less than a quarter of an hour, and the fusion of one kilogramme of steel is effected within, say, another quarter of an hour, successive fusions being made in somewhat diminishing intervals of time." He finds that there is an efficiency of 33 per cent. "The electric furnace has," he says, "the following advantages in its favour:—(1) That the degree of temperature attainable is theoretically unlimited; (2)

that fusion is effected in a perfectly neutral atmosphere; (3) that the operation can be carried on in a laboratory without much preparation, and under the eye of the operator; (4) that the limit of heat practically obtainable with the use of ordinary refractory materials is very high, because in the electric furnace the fusing material is at a higher temperature than the crucible, whereas in ordinary fusion the temperature of the crucible exceeds that of the material fused within it." The Siemens electric furnace had the electrodes arranged vertically as shown in the figure.

As the charge fused, the arc played between it and the upper electrode. The regulation of the position of the upper electrode was effected by a solenoid and dash-pot similar to the arrangement then in use for arc lamps. A later pattern had the electrodes inserted through the walls of the crucible horizontally.

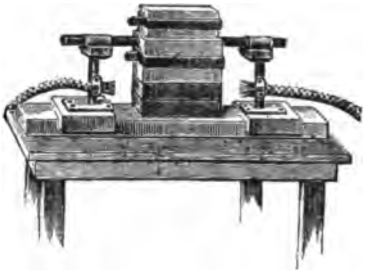


FIG. 53.—Experimental Furnace

A small laboratory arc furnace is shown in Fig. 53, the two carbon rods sliding by hand on a wooden base. Such furnaces may be readily built up of ordinary fire-bricks and fire-clay. For smaller furnaces a lump of chalk may be used, being hollowed out to form a crucible, and two holes drilled in the sides to pass the carbon rods, to form an arc above the materials to be heated.

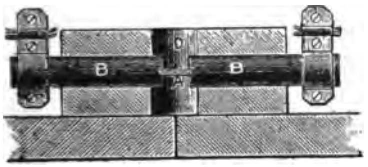


FIG. 54.—Experimental Furnace

In Fig. 54 we have the simplest form of resistance furnace, formed of a block of chalk drilled to form a crucible; and to take two thick carbon rods B, B; the two rods are joined in the crucible by a thinner rod of carbon. On passing current, this thin rod becomes incandescent, and the materials filled in round it become highly heated.

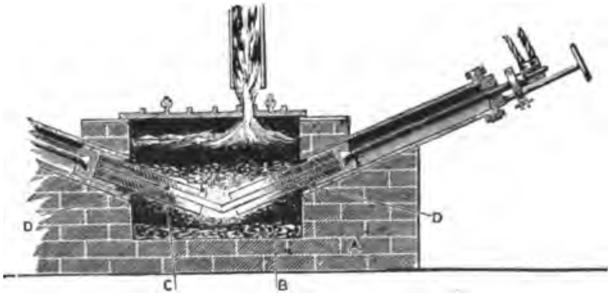


FIG. 55.—Cowles' Furnace

This resistance method is also largely used for electric cooking apparatus, a metal wire being embedded in enamel, attached to the pot, pan, or oven sides, and this wire is heated by the current.

A third system is that wherein the materials to be treated are the resistances themselves. The materials are placed in a furnace between two electrodes, as shown in Fig. 55, and they become heated and fused by the current passing through them. This is known as the Cowles process.

In the Wilson furnace we have a simple form of the Siemens. In this furnace carbide of lime is made. It is shown in Fig. 56.

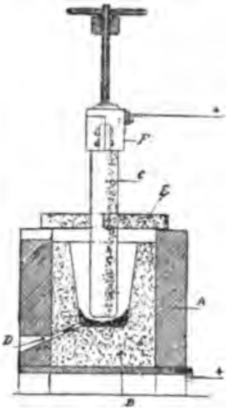


FIG. 56.—Wilson's Furnace

There is a casing of fire-brick A, a carbon vessel B, with a tapping hole D, and a cover E, through which passes a carbon electrode C, adjustable in height. The charge is introduced little by little, and as it is heated, fuses, forming a pool of calcium carbide, acting as the electrode, between which and the carbon rod an arc is maintained. The tapping hole allows the fused product to be run off, and thus should permit the furnace to be worked continuously. For the successful attainment of this end, however, a considerable modification is needed, the hearth being much shallower, and the tapping very frequent. The high fusing-point of calcium carbide makes all continuous processes depending on its being run out from the zone of formation somewhat difficult to work. Thus it comes about that most carbide is "block" carbide.

Another form of furnace provides for feeding in raw material, which, making contact with the inner carbon lining B and the electrode A in Fig. 57, becomes heated before being exposed to the arc. The illustration is a design of Mr. B. Blount's.

The Alkali Company of Widnes makes carbide in a somewhat similar furnace.

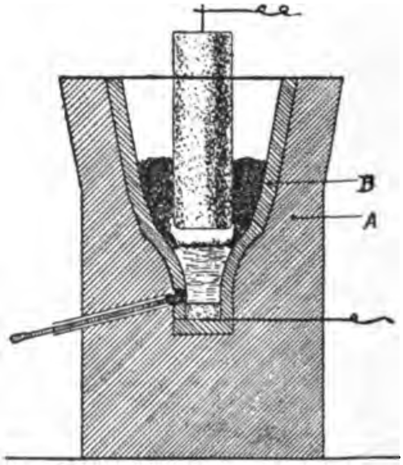


FIG. 57.—Blount's Furnace

The distinctive merits of this furnace are, that the upper electrode is continuously immersed in the raw materials, and that the vessel containing these is slowly rotated so as to bring every part of the charge into the zone of activity. Thus there is maintained a constant supply of raw material immediately beneath the upper electrode, and no arc can form. The furnace is of the resistance or Cowles type, and the waste involved by the use of an open arc is avoided. In this way a block of carbide is gradually built up by feeding in fresh raw material (which may be done mechanically) and raising the upper electrode. When the block is finished the operation is stopped, the front of the crucible opened, and the block removed. Adherent raw material from the sides, and crude carbide containing admixed raw material from the top, are knocked off, and the sound, well-fused block carbide broken up for packing.

Another form of Siemens furnace is shown in Fig. 58. It is built entirely of non-conducting materials; the upper electrode is water-jacketed, the lower is let into the bottom; a fire-clay tube leads off the products, such as phosphorus, which distils over.

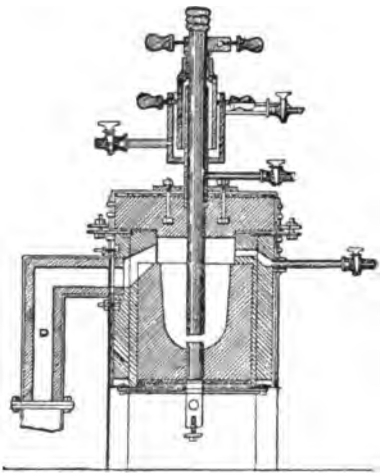


FIG. 58.—Siemens Furnace

In all these furnaces about 100 volts pressure is sufficient, and as the cost of current is the main cost, the cheapest possible source is necessary. The steam-engine is out of the question altogether; water power, fuel gas, or fuel-oil engines alone can compete. It is very doubtful if any water power in this country would produce power cheaper than a Diesel engine using crude oil at the port of consignment, with merely the shipping carriage to pay. The Texas liquid fuel is delivered at the wharf for 36s. per ton, equal to 1¾d. per gallon. At these prices one brake horse-power costs one-tenth of a penny, a 50 B.H.P. engine can be run for £65 per annum for sixty hours per week. No water power in this country of equal power could be rented for that money, not to speak of other costs. The flash-point of Texas liquid fuel is 170°. Another difficulty in this country is the cost of transport of fuel. Carriage in tank waggons costs 2s. 6d. to 7s. 6d. per ton, according to distance, so that for these reasons electric furnaces should be erected only within easy reach of the shipping wharves; it costs more to bring the fuel from London to Leeds than it does to bring it from Texas to London.

Another application of electrical heating is to that of welding metals. There are three processes, the arc, the resistance, and the electrolytic. In the arc system the article to be operated upon is connected to the positive pole of a 100-volt generator, and a carbon rod is connected to the negative pole; the parts to be heated are touched with the rod and an arc struck of about ¾-inch length; this arc is then drawn along the joint or seam to be welded, much in the same way as a plumber works a blowpipe in lead-burning. Care must be taken to shield the skin of the hands, arms, and face from the light, as it causes the skin to peel off; and, of course, the eyes must be thoroughly protected by smoke-coloured glasses.

The resistance system of Prof. E. Thomson is much more generally useful, and employs a low-pressure current of large volume.

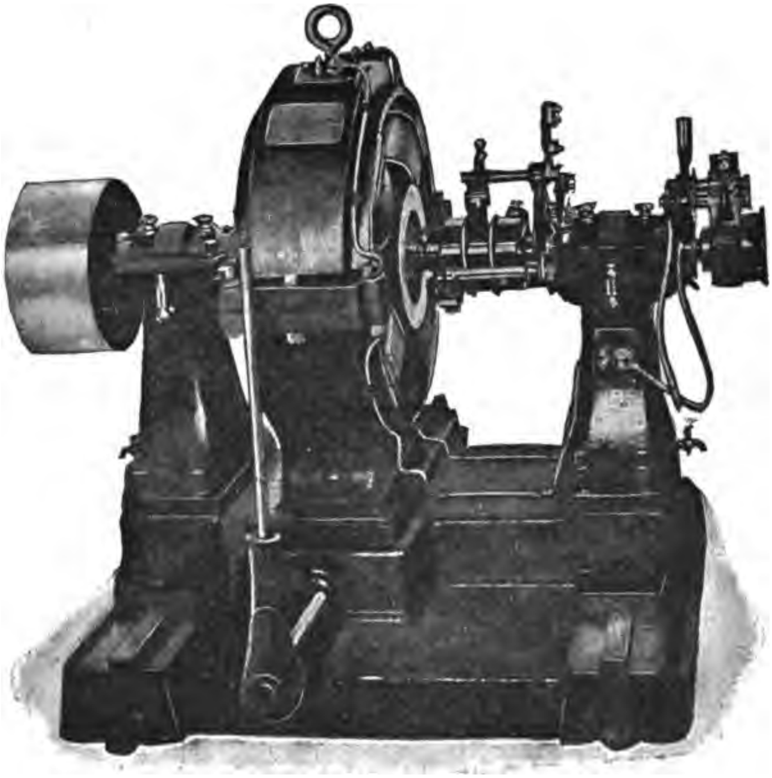


FIG. 59.—Welding Generator

For this reason attenuating current is used, so that it may be readily transformed to any desired pressure and current.

The principle involved in the art of electric welding, as invented by Elihu Thomson, is that of causing currents of electricity to pass through the abutting ends of the pieces of metal which are to be welded, thereby generating heat at the point of contact, which also becomes the point of greatest resistance, while at the same time mechanical pressure is applied to force the parts together. As the current heats the metal at the junction to the welding temperature, the pressure follows up the softening surface until a complete union or weld is effected; and as the heat is first developed in the interior of the parts to be welded, the interior of the joint is as efficiently united as the visible exterior.

The objectionable electric arc is not employed in the Thomson process, and differs radically from it in forcing through the metal to be heated electrically such volumes of current that its own resistance is sufficient to bring every molecule of the section traversed by the current to the desired temperature.

In the arc welding process the heat is generated either in the surrounding envelope or communicated to the metal by conduction, or in the contact between the metal and another high resisting medium. The operator is compelled to protect himself by keeping the exposed portions of the body covered, and to use thick coloured glass, and even then is in danger of seriously injuring the eyes. Not being able to see to advantage, his work is necessarily uncertain and unsatisfactory.

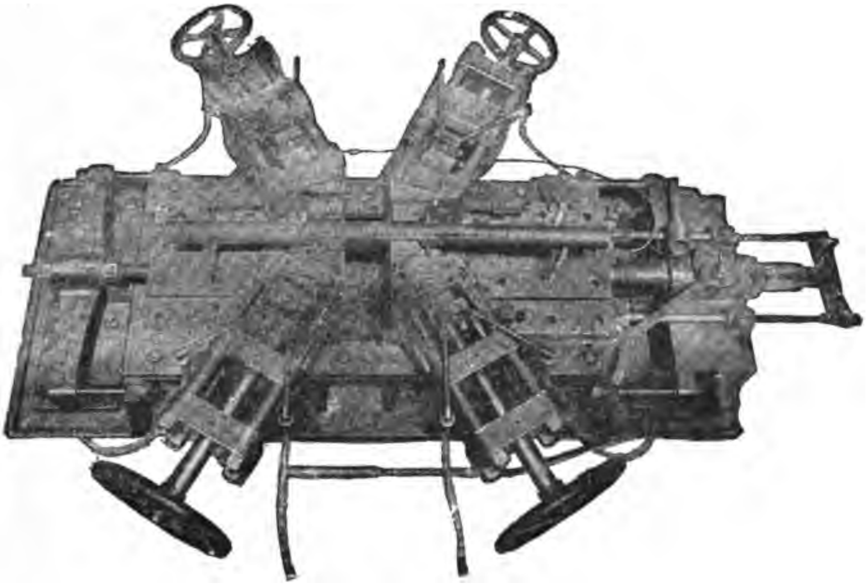


FIG. 60a.—Electric Welder

Besides the waste of power in the flame of the arc, which is not in contact with the metal, the flame itself gives out noxious fumes of an irritating character. The Thomson process is entirely free from all these objections.

An electric welding self-exciting alternator is shown in Fig. 59, as used in this process. The machine has a rectifying commutator for exciting the field magnets; it is belt-driven. The transformer generally forms part of the welding machine, as the clamps for holding the work are coupled direct to the secondary terminal. The welder consists of a transformer provided with suitable clamps to tightly grip and hold in place the pieces to be welded, and mechanical, hydraulic, or other device by which the abutting ends or surfaces of these pieces are forced together. In the smaller types, the pressure is applied and the current shut off automatically. In all but the smaller types, provision is made to maintain a circulation of water in the secondary circuit for cooling purposes, and a reactive coil for controlling the current in the welder in varying sections of stock to be welded; and a breakswitch, by means of which the circuit is opened and closed in the primary of the welder—in some types, automatically; and switches and wire, for the main line.

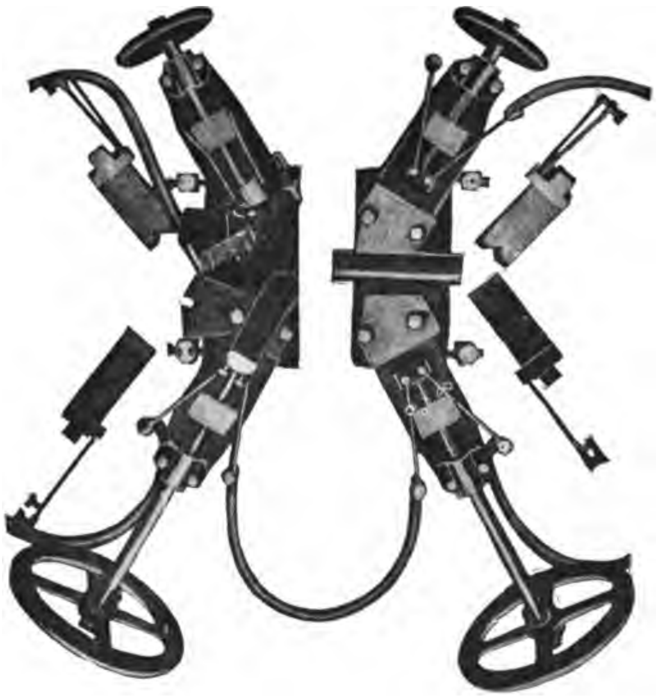


FIG. 61.—Welder Clamps

The power required for the different sizes varies nearly as the cross sectional area of the material at the joint where the weld is to be made. Within certain limits, the greater the power the shorter the time; and *vice versâ.*

The following tables are based upon actual experience in various works, and from very careful electrical and mechanical tests made by reliable experts. The time given is that required for the application of the current only:—

Power for Electric Welding

ROUND IRON OR STEEL.

Diameter.	Area in square ins.	H.P. applied to Dynamos.	Time in seconds.
¼ in.	.05	2.	10
⅓ "	.10	4.2	15
½ "	.22	6.5	20
⅝ "	·30	9·	25
¾ "	·45	13·3	30

EXTRA HEAVY IRON PIPE.

Inside diameter.	Area in square ins.	H.P. applied to Dynamos.	Time in seconds.
½ in.	·30	8.9	33
¾ "	·40	10.5	40
1 "	.60	16.4	47
1¼ "	·79	22.	53
1½ "	1.10	32.3	70
2 "	1.65	42.	84
2½ "	2.25	63.7	93
3 "	3·	96.2	106

GENERAL TABLE.

IRON AND STEEL.			COPPER.		
Area in square ins.	Time in seconds.	H.P. applied to Dynamos.	Area in square ins.	Time in seconds.	H.P. applied to Dynamos.
0.5	33	14.4	.125	8	10
1.	45	28.0	.25	11	23.4
1.5	55	39.4	·375	13	31.8
2.	65	48.6	·5	16	42
2.5	70	57.0	.625	18	51.9
3·	78	65.4	.75	21	61.2
3.5	85	73.7	.875	22	72.9
4·	90	83.8	1.	23	82.1

The welder shown in Fig. 60 has all the most recent improvements, on a horizontal table, with oblique clamps; these are shown in more detail in Fig. 61.

Electrical heating for cooking has been introduced, and to some extent used by wealthy people. The cost of electric cooking is very high compared with gas cookers. This must be so, as the electricity represents only a very small portion of the energy of the gas, oil, or coal consumed to produce it. It is used for small purposes, such as heating a tea-pot or coffee-pot. An electric kitchener is shown in

Fig. 62, consisting of a hot-plate heated by resistance wires or strips.

In some tramway or street-railway lines in America they heat the cars by electric heaters in winter time. The North American winters being severely cold, artificial heating is necessary; and considering the conditions, even at the high cost of energy expended, the electric heating has many advantages over coke or gas stoves or hot-water vessels in closed carriages.

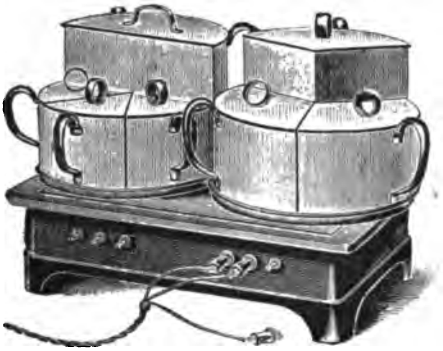


Fig. 62.—Electric Cooker

In chemical laboratories electric heating has many great advantages, as the heat can be so nicely adjusted to any temperature fixed upon; and by means of platinum wires, spirals, or carbon rods, heat can be applied much more exactly to the matter under treatment than by flames. For laboratory purposes low-pressure should be used, either from a transformer or from storage cells; not more than 10 volts are required.

Figs. 63 and 64 show the G. E. C. of Manchester's electrically-heated soldering bits. Fig. 63 is heated by resistances, while Fig. 64 shows a bolt heated by an internal arc. The former consists of a copper body, surrounded by resistance wires, which are protected by a metal shield. The connecting wires are led out through the handle. The bit is screwed into the body and heated by conduction; it can be removed without disturbing the electrical connections. These irons are made in 2 and 3 lb. sizes, taking 1 to 2 amperes at 100 volts.

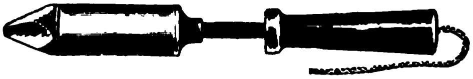


Fig. 63.—Electric Soldering Iron

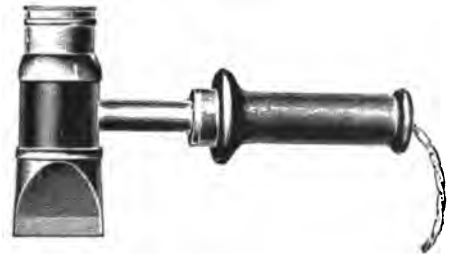


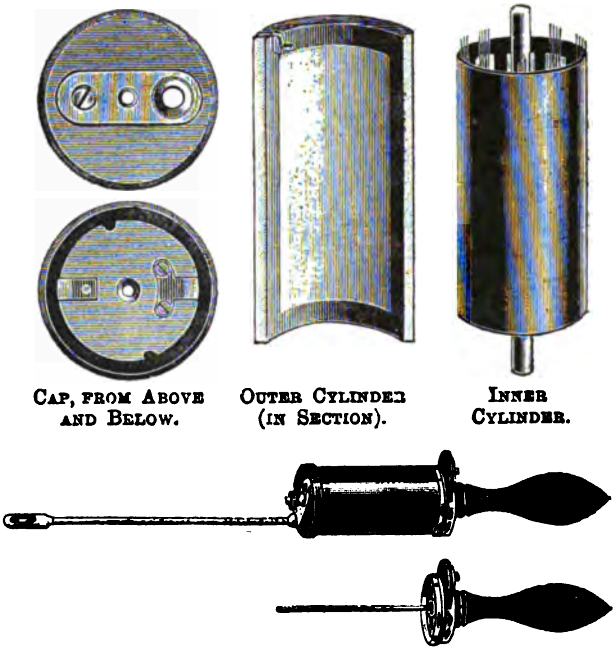
Fig. 64.—Electric Soldering Iron

The other weighs 3 lbs. upwards, and takes from 4 to 6 amperes at 45 volts, with the normal resistance in series; in this case the copper bit is the positive and the carbon the negative electrode. The carbon is put into a spring holder, the current switched on, and a knob pressed and released. This strikes the arc, which is maintained for half an hour, when the arc must be renewed. Ordinary arc lamp carbons are used.

Gas Igniter

Gas igniters are also classed under heating by electricity. Many of this class are used in igniting the charges in gas-engines, some magnetos, some induction coils; these are of some interest in gas-engine plants, although the tendency now is towards self-ignition by high compression and temperature, as in the Akroyd and Diesel engines.

For lighting gas-lights an electric lighter has much usefulness, especially to warehouse and factory owners. Portable electric gas-lighters have been in existence for some thirty years, but many of them have required constantly recharging and repairing. In order to avoid these difficult and costly repairs, Messrs. Nehmer Brothers have not only done away with the complicated pusher, speed wheel, and ratchet mechanism, but also with the tin and copper foil connections. In addition, they have altered the arrangements of the static system, and discarded the neutralising bridge. This new departure from the usual type of influence machines has the advantage that a very brief rotation of the inner cylinder generates enough sparks to light the gas. The friction is almost *nil*, and in consequence of this the lifetime of the apparatus is considerably increased.



Cap, from Above and Below.

Outer Cylinder (in Section).

Inner Cylinder.

Handle.

Fig. 65.—Electric Gas Igniter

When taken to pieces, the new lighter consists really only of four parts, viz., the handle or body, the inner cylinder, the outer cylinder (in section), and the cap with its spire in Fig. 65.

The body consists of a handle, to which a friction wheel is fastened; there is a long steel rod right through its centre, which forms the spindle, and serves as support for the other three parts.

The inner or rotating cylinder is made of vulcanite. Lengthwise to its inner surface are fastened eight strips of tinfoil, with fine metal wire brushes attached to the end of each. The axle of this cylinder is a brass tube, with a shaft cushion at each end; this fits on the spindle, and is set into rotation by the friction wheel.

The outer is a larger stationary vulcanite cylinder, which fits over the other one. To its inner surface are fastened two field plates, provided with two wire extensions, against which the brushes strike in rotation, and so replenish the charges on the field plates. The remaining part is a vulcanite cap, which fits on the outer cylinder, and is screwed down by a nut. It supports the spire on one side, and has fastened to the other sides two solid metal blocks, which are connected with the sparking points, and fixed in a diametrical position in such a way that the brushes strike them in rotation, and convey the electricity to the top of the spire.

It cannot fail to continually work properly, as the charge is generated by the person using the lighter without any intervening mechanism. All the connections are such as to last almost for ever, and wire brushes of the kind described have stood the test for many years.

Electric heating is also applied to hospital surgery work for cauterising and amputating growths, and in some cases it has been found useful in maintaining an even temperature applied to the patient, in place of fomentations and other hot applications.

Electrolytic heating has been already described in Vol. I. for forging purposes, and it may be further extended in usefulness. It must be pointed out that the electric pressure required must be at least 120 volts *between the electrodes in the cell.* Some experimenters have failed, even although they used a dynamo giving 150 volts on open circuit, because, owing to fall of pressure when a large current flows, the pressure has fallen at the cell to 100 volts or less. It is always advisable to have a voltmeter across the cell, to indicate the actual pressure when the article to be heated is plunged in.

The common incandescent electric lamp is simply a resistance or carbon wire heated by the current; but the Nernst incandescent electric lamp, also described in Vol. I., is an electrolytic resistance heated by electricity.

Many electrolytes are non-conductors when cold, but conduct when hot. Melted glass is a fairly good conductor.

Since describing in Vol. I. the Nernst lamp, it has been fully described by Mr. Wurtz before the American I.E.E., December 14, 1901. They are made from 50 to 2000 C.P.

The following table, from the German Standardising and Testing Institute tests, shows the particulars at 220 volts:—

Nernst Lamp Economy

Time (hours).	Current (amperes).	Candle Power.	Per Cent. Decrease in Candle Power.	Watts per Candle.
0	0.264	35.1	0	1.65
50	0.261	32.4	7.7	1.77
100	0.260	32.3	8.0	1.77
200	0.253	30.1	14.0	1.85
300	0.242	27.5	21.6	1.93
400	0.237	26.5	24.5	1.97
Mean during 400 hours	0.251	30.1	...	1.83

These results are for straight filaments. Curved filaments gave a mean watts per candle of 1.57 for a mean candle-power of 35; current mean = 0.245.

Perhaps it may interest some to briefly refer to the thermopile. It has always interested electrolytical electricians, although it has hitherto failed to come up to expectations.

The reasons for failure are two. One is the seemingly insurmountable barrier met with at the outset, when we find that the thermo-active elements are of very high resistance electrically, and that the higher the thermo-electric power, the higher this resistance is also. Some years ago I investigated the subject practically, with the result, that while the pile gave much greater output per pound of materials, and was more durable than the older piles, the efficiency was not over 5 per cent. at full load, and full load was taken to be the current when the internal and external resistances were equal, so that half the actual energy was lost in the pile itself. A pile is like a steam-engine and boiler: the whole of the heat of the furnace can be accounted for thus—a large portion goes up the chimney, as the flue gases must be at least as hot as the hot side of the pile; the greater portion is lost by conduction through the pile from the hot to the cold ends; and a small portion appears as electrical energy.

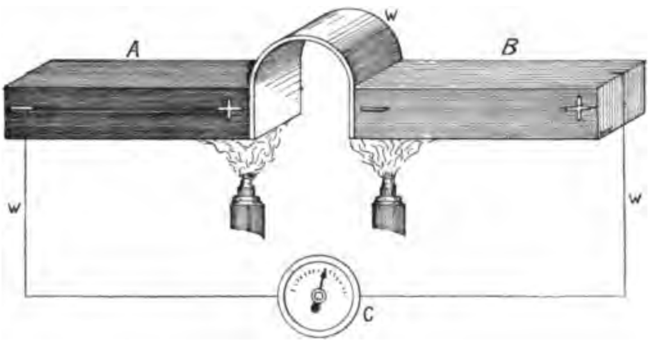


FIG. 66.—Thermo-Electric Bars

Briefly, the pile consists of thermo-electric blocks or bars of the most active materials known, in series connection.

The usual form is that made up of two metals, one of which becomes positive at one end when heated, joined to another metal which becomes negative at the heated end.

If a bar of active metal is heated at one end it becomes either positive or negative at the hot end, according to the metal used, and, of course, negative or positive at the other cold end.

Some metals become positive at the hot end and some become negative, hence we can make a series of bars, joining all the bars + – + – + – and so adding their electric pressures. Fig. 66 shows two bars, a bar A, which becomes + at hot end, joined to a bar B, which becomes – at hot end. The joining wires, w, w, w, make no difference, whatever the metals they may be made of. Fig. 67 shows the common arrangement with two metals, A and B.

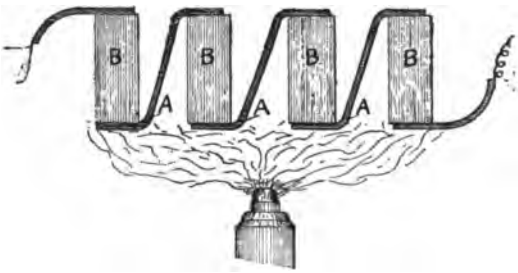


FIG. 67.—Thermopile

Cox's pile, which gained some notoriety, is shown in section in Fig. 68. It consisted of bars of a mixture of zinc and antimony, two of antimony to one of zinc, and these bars joined by flexible tinned iron, cast into the end of the bars, same as used in Clammond's pile.

This mixture seems to be the best alloy or metal yet discovered, and, unfortunately, it has very bad properties mechanically and physically. First the mixing and casting of the bars is very difficult; both metals are easily oxidised when melted, and do not readily mix thoroughly; the alloy is as brittle as cube sugar, it is difficult to unite to the other metal, it expands on cooling. For these reasons, the maintenance of good electric contact at the joints cannot be assured.

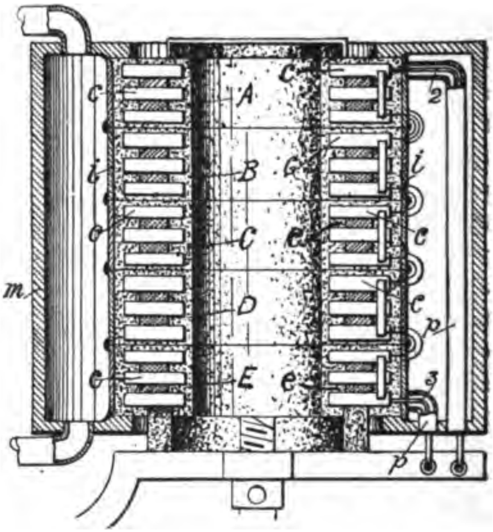


FIG. 68.—Cox Thermopile

The Gulcher pile has, by good design and construction, overcome many of the difficulties, employing slabs and sheets of metals bound up in a cast-iron frame; it is shown in Fig. 69 with fifty couples. This size gives an external pressure of 1.5 volts, with a current of 3 amperes, the internal resistance being 0.5 equal to the external, and in doing this work consumes 5 cubic feet of gas. This return is very small, 5 cubic feet of gas for 4.5 watts work done, yet its convenience and simplicity go a long way to compensate for cost.

According to this result, 1000 cubic feet of gas would give about 1 B.O.T. unit, which in Leeds would cost 2s. 3d. per hour for gas.

The high internal resistance is a great drawback. My own experiments were directed towards the reduction of this resistance, and the maintenance of good electric joints. The first consideration of resistance internal is one of considerable complexity, and may first be looked into from the thermo-electric power and specific resistances of the metals in a series. Beginning with the highest positive and lowest negative with lead neutral, the thermo-electric power of a metal means the E.M.F. per degree Centig. for a pair made of that metal with the standard metal lead. In the Table B., microvolts are given per degree difference. The specific resistance is the resistance in microhms of one cubic centimetre of the material.

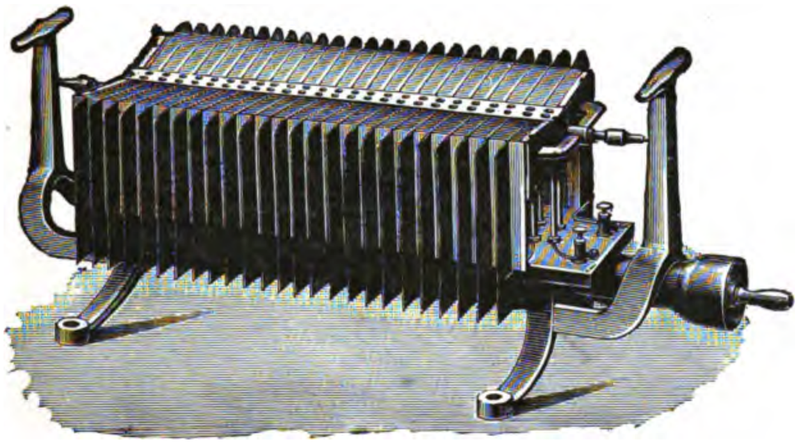


FIG. 69.—Gulcher Thermopile

TABLE B.

	E.M.F.	Specific Resistance.	Current.	Watts.
+ Bismuth	90	130	0.692	62.28
Nickel	22	12	1.833	40.32
German-silver . . .	11.75	30	0.391	4·59
Lead	0	...	...	...
Platinum	0.9	11	0.081	0.07
Copper	1.36	1.6	0.85	1.15
Zinc	2.3	...	...	...
Iron	17·5	9	1·944	34·02
− Antimony	25	35	0.714	17.85

Now, the resistance of the metal and the thermo-electric power are two very important factors, and in Table B. I have set out some figures illustrative of the relation of these quantities. The metal is supposed to be one cubic centimetre, and placed between the poles of a horseshoe of lead, which for present purposes may be assumed to have no resistance and no E.M.F. (see Fig. 70). In each case the metal active has one junction with the lead raised one degree in temperature above the other junction. In the first column is the resulting E.M.F. in microvolts; in the second, the specific resistance in microhms, and according to $\frac{E}{R} = C$, we get the current developed in the circuit; in the third column, and by $C \times E$, we get the power in microwatts developed, all, however, in internal work; so that the commercial efficiency is zero under these circumstances.

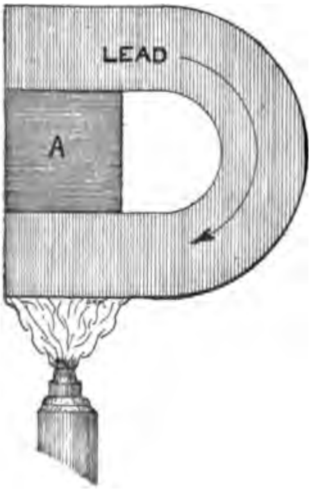


Fig. 70.—Thermo Tests

This table shows that the metal giving the highest E.M.F., even although it has a higher specific resistance, converts the largest amount of energy into electrical energy, for the heat resistance is nearly proportional to the electric resistance in each case. Thus bismuth, with an E.M.F. of about 90, and a Sp.R. of 130, develops about 63 M.W.; while iron, with as low a resistance as .9, and an E.M.F. of 17.5, develops about 34 M.W. on short circuit.

But if we are to use thermopiles, we want energy in the external circuit so that we must take some external resistance into account, and we take that resistance as equal to the internal and then proceed with the comparisons again. But to make this inquiry complete would entail a complete knowledge of the rate of flow of heat from the hot ends of the metals or active materials to the cold ends. Unfortunately this knowledge is not yet available, and much patient and costly research is still necessary in this part of the subject. However, from what data is available we can indicate the principles of the methods adopted in this investigation. From several reasons, principally that due to the use of three metals, or two active materials and one metal in the improved pile, it is necessary that the quantity of heat flowing per second through the active plates or bars or cubes from hot to cold ends should be the same in each.

But as may be seen from the following table, the conductivity of the materials is very different for heat:—

Copper	100
Steel or iron	12
Antimony	16
Bismuth	1.8

So that if the bars or plates were of equal thickness from hot to cold ends, and say one material was antimony and the other bismuth, about nine times more heat would pass through the antimony than through the bismuth, and this would create a difference of temperature between the ends of the copper-connecting strip at the cold ends.

Now if we take a bismuth cube centimetre which from Table B. has E.M.F. $= 90$, $R = 130$, $C = 0.7$, and the micro-watts with external and internal R equal would be $\frac{90}{260} \times 90 = 31$ micro-watts external energy.

Now an iron bar 1 square centimetre section and 7 centimetres long would pass the same quantity of heat in same time as the cube centimetre of bismuth. Its E.M.F. would be 17.5, $R = 9 \times 7 = 63$; and if external and internal were equal in resistance, the total energy in external circuit would be 0.135 micro-watts.

Now for an antimony element, E.M.F. $= 25$, the relative conductivity of iron and antimony is as 12 to 16, so that as the iron was 7 centimetres long to compare with bismuth, we must make the antimony $\frac{4 \times 7}{3} = 9$ centimetres long to offer the same resistance to heat as the bismuth cube and the iron bar did. Its resistance would then be $35 \times 9 = 315$, and energy in external circuit $\frac{25}{630} \times 25 = 1$ nearly.

Fig. 71 is a diagram showing the active blocks of the different lengths for the purpose of equalising the temperatures at the cold ends. Unfortunately, the researches into heat conductivity and the electrical specific resistances and thermo-electric powers are not known for the most active materials except bismuth and antimony, and the whole subject requires further research from a practical point of view, and calculations made, as in the above examples, taking heat conducted into account. For further information Prof. Tait's works and Everett's C.G.S. Units may be consulted.

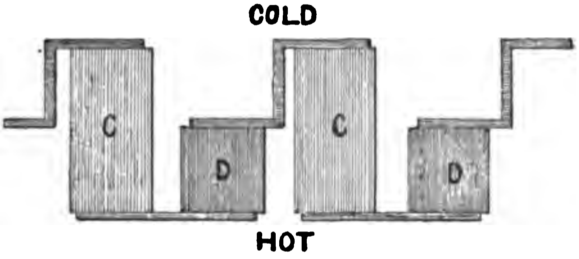


Fig. 71.—Thermopile Diagram

But these figures teach us something upon the construction of thermopiles, the practical part we have to deal with.

The active materials known are very limited, their thermo-electric properties are:

	Value.	Sp. R.
+ Bismuth	90	130
+ Nickel	22	12
– Iron	17.5	9
– Antimony	51	35
– Clammond's alloy	250	Unknown
– Tellurium	502	Unknown
– Selenium	800	6×10^{10}

Selenium is the highest in value, but has an enormous resistance. It has been used as a thermopile for recording or observing slight changes of radiant energy. Thus a pile of selenium will send a slight current through a detector of great sensitiveness by the energy of a beam of light from a candle hundreds of yards away. Bell's photophone and the photoscope for seeing or transmitting visible pictures depend upon the high thermo-electric value of selenium.

Tellurium comes next in power, and has been used for photo-electric work also, but what its specific resistance may be I cannot find out. It is one of the rarer elements, and of no use in the arts or industries. Clammond's alloy is the best-known metal as negative yet discovered.

Bismuth is the highest positive metal. Other elements, such as the artificial copper sulphuret, value about 1000 micro-volts, but its Sp. R. is unknown.

Galena is highly positive, but its values are unknown, except as given by Prof. von Stephan, that 6 pair of galena and copper pyrites gave 1 volt.

Galena is the common lead ore, the sulphide or sulphuret, and copper pyrites is the common yellow ore of copper found in Cornwall and Devon. The thermal and electrical constants for these mineral elements are not known, further than those vaguely given by Becquerel for the artificial sulphuret, and by Stephan for the natural sulphurets.

It is stated that 8 couples of natural sulphuret of copper and lead at 300° difference give 1 volt. This would amount to $\frac{1}{300 \times 8} = 417$ micro-volts per degree difference if correct.

There is a wide field for research in this line of minerals to ascertain their resistances and E.M.F. accurately. My own researches are not sufficiently reliable owing to the lack of accurate measuring apparatus and difficulties due to research in private laboratories. The results, however, are consistently encouraging.

Apart, however, from research as to the best active materials, there is the equally important inquiry as to the best construction of the pile. This question has been pretty well settled in the research we made.

In the first place, the ordinary construction shown in Fig. 67 is bad, for the conducting strip, generally of iron or German silver, is a good conductor of heat, and to keep down electrical resistances must be of considerable cross section. It therefore offers a free and easy path for a large useless flow of heat from the hot to the cold ends, and adding little to the terminal E.M.F., for these materials used for this connecting strip have a very low value thermo-electrically.

In the next place, the really active materials are far too long from hot to cold end in previous thermopiles. The efficiency of a pile depends on the watts delivered in the external circuit, and inversely as the heat conducted from hot to cold ends.

If the bars are very long, for instance, the heat may be radiated sideways before it reaches the far end, so that it remains at a constant low temperature. This is an extreme case of too long a bar. Its electric resistance may be 1 ohm. If we cut it down, its electric and heat resistance will decrease together; therefore more heat will be conducted through the bar, if we keep up the same difference of temperature, between its ends, by some cooling appliance at the cold end. If we halve the length, the flow of heat may be doubled, but the resistance will be halved.

The flow of heat is not, however, proportional to the length of the bar.

The electrical resistance can only be decreased by making the bar shorter and greater in cross section, and both of these proceedings will nearly equally increase the heat flux; the higher the conductivity, the longer the bar must be. On the other hand, the short bars, while passing more heat, give a greater output in watts per lb. of material. We cannot go into this question minutely until some data are available as to the heat conductivity of the active materials is known.

Experiment proves that the short length of active material of low heat conductivity is best, and I have meantime taken as a standard thickness one centimetre of bismuth, and other materials to be made thicker in proportion to their heat conductivity. By thickness is here meant distance from hot to cold ends.

The pile to overcome the first constructional difficulty should consist of three metals, two active, a positive and negative, and one to act as a conductor only, and be thermo-electrically neutral.

Thus let us take bismuth and Clammond alloy as the two active materials, and copper as the conductor, and arrange them as in Fig. 72. I am assuming the Clammond alloy and bismuth to have the same heat conductivity, and therefore both materials are equal in thickness. As the copper has practically no electric resistance in this arrangement, and does not conduct heat from one hot end to the next cold end, as in all previous arrangements, it may be neglected altogether. The point next to observe is that all the heat flows through the active materials; this is a great improvement on old piles.

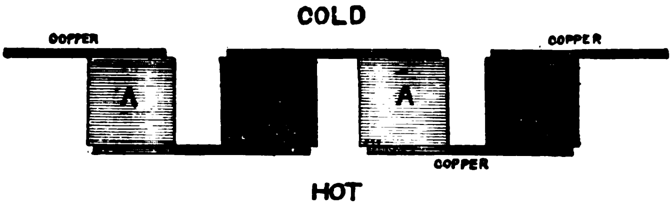


Fig. 72.—Thermo-Electric Materials

A couple like this with two cubes of bismuth and Clammond joined up, as shown in Fig. 73, and a small compass placed inside, will act as a heat indicator; even if the hand is brought near the upper or lower copper strip, it will deflect the needle.

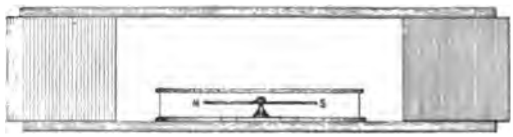


Fig. 73.—Thermoscope

The next difficulty to be overcome in the use of high-power elements has been already alluded to, the good electric connection at the junctions, which is an absolute necessity, and so very difficult to attain.

Elements such as bismuth, antimony, Clammond alloy, copper sulphuret, galena, and others, do not make good soldered joints direct; nor do they weld perfectly, nor can pressure be applied to squeeze them into good contact. This difficulty was overcome in our investigations by first electroplating their faces with a sound, solid coating of copper or silver. With some care this proved a success, for the neutral copper strips could be securely soldered to the active materials to which the deposited copper firmly adhered.

The next question arose as to how to produce the necessary difference of temperature, the heating and cooling. This question also bristled with difficulties which are not yet entirely disposed of.

The best system for producing a great difference of temperature is to use liquid air to lower the temperature of one face and boiling water for the other. This would be most satisfactory but for the great cost of liquid air.

The next best system is to use water, as cold as it can naturally be obtained, and hot oil or glycerine or air for the heater, and the next to that cold air with the same heaters.

The air cooling, though not so effective, is the best of the last two, for the application of cold water raises insulation difficulties at the cold ends.

An experimental pile on these principles is shown in Figs. 74 and 75. The shell of the heater is of thin copper, the elements are bound round the outside in bands, and insulated therefrom by thin asbestos paper. The outer connections from element to element are made of flexible stranded copper cable, the inner connections by copper strips. The interstices between the elements are filled with asbestos or slag wool, so that freedom is allowed for expansion and contraction.

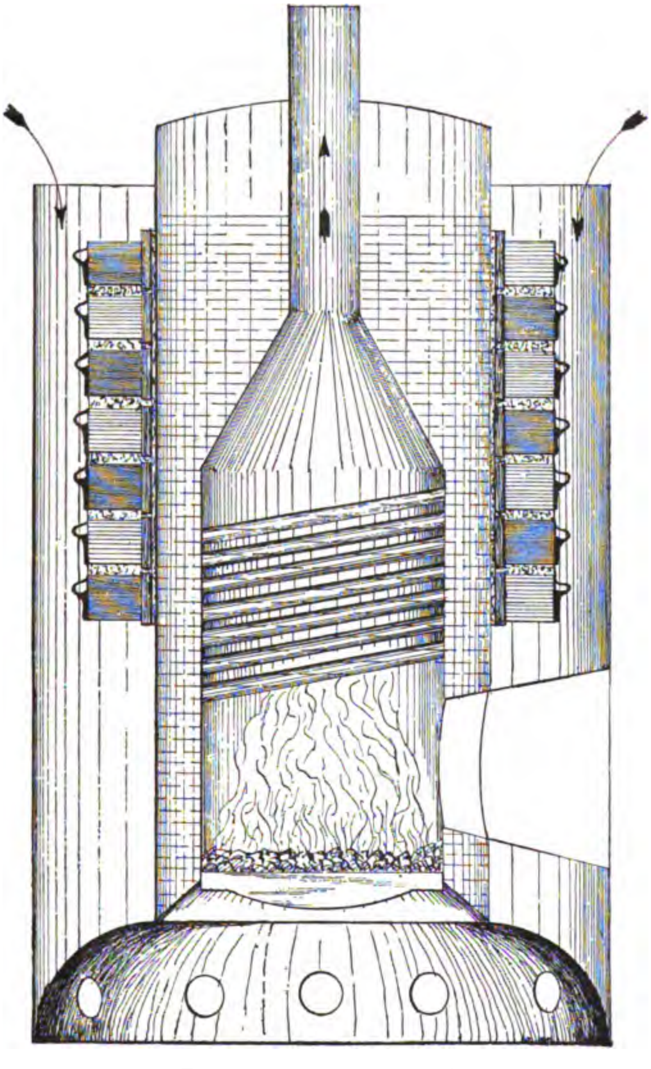


FIG. 74.—Thermopile Elevation

Thermopile Construction

The central fire maintains an even temperature in a fluid oil or glycerine, and the cold air for the supply of the fire is drawn down through the cold ends into a closed ash-pit.

The heat required is only sufficient to keep up the fixed temperature. The oil for the fluid should be that almost worthless residue left in the petroleum retorts after all the volatile ingredients have been distilled over. This is a permanent fluid at the high temperature. Lard oil and tallow oils will stand temperatures of 450° Fahr., their boiling-point being between 500° and 600° Fahr.; they are more costly, however. The calculations as to the power and output of large thermopiles built on scientific principles can be made electrically.

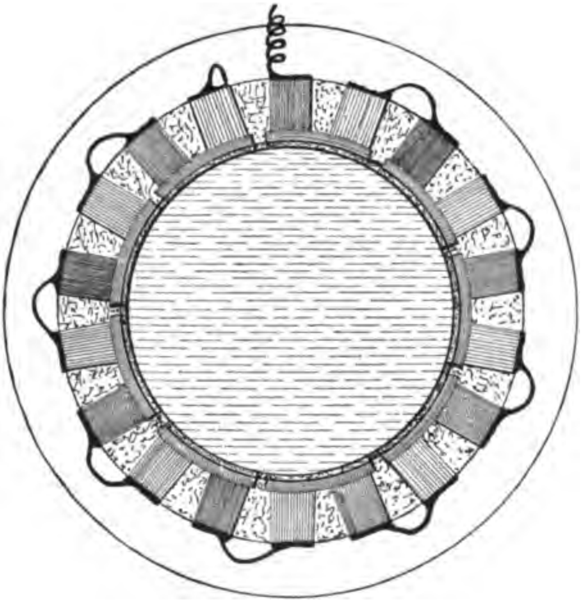


Fig. 75.—Thermopile Plan

But the thermal data required is not available to enable efficiencies to be calculated. A large pile consisting of a battery of four piles, containing each 400 couples or 800 active cubes, would give 100 volts on open circuit. The internal resistance would be 5 microhms per cube or plate, $= 3200 \times 5^{-6} = 0.016$ total ohms. The internal resistance would be probably, due to the temperature, actually 0.02. We might make the external ten times this, 0.2, total = 0.22 ohms, giving current $= \frac{100}{.22} = 450$ amperes total, and the external volts would be 90. As the internal resistance is $\frac{1}{10}$th total R, the K.W. output would be, according to these figures, 450 × 90; 40,500 = 40.5 K.W.

The data taken are based on results obtained by experiments, so that theoretically there is, from an electrician's point of view, no impediment to a practical realisation of the direct conversion of heat into electricity. Further investigation into the thermal side of the practical question is required to complete the inquiry.

This thermo-electric generating question has been considered somewhat fully for several reasons. First, it is a subject requiring bringing up to date; and secondly, the progress made in any direction in science is always worth recording; and thirdly, it is well to direct attention to difficult unsolved problems—in fact, this is a more important service than merely describing what has been solved or accomplished already.

In the foregoing calculations the theoretical values are taken, and some deductions would require no doubt to be made in practice, but still the results would be satisfactory. From what can be gathered from engine-boiler experience, the heat lost by conduction would not be excessive. The piles calculated are each 2 feet 10 inches diameter outside shell of boiler or heater, and the active couples cover a height of 4 feet of this shell. The heat radiated from this surface, which has an area of 48 × 110 inches, through the active couples might be estimated, but only roughly. It might be about that lost from a boiler of same size with steam up, but not working. The only way to settle the question is by actual experiment. In 1879 M. Clammond described the pile shown in Fig. 76 before the Paris Academy. It is built over a coke fireplace. According to the description of an electrician about that date it had 3000 elements. According to this, at 20 elements per volt it should have given 150 volts, but this electrician says it gave 109 volts, and that two of them gave a pressure equal to 120 Bunsen cells and burned 22 lbs. of coke per hour. A Bunsen cell gives 1.75 volts nearly, so that $1.75 \times 120 = 210$ volts; each pile had the enormous resistance of 15.5 ohms for 109 volts, so that if the arc light of 40 carcels power which it is said to have worked took, as arc lights usually did, 50 volts, 59 volts must have dropped in the pile. From this we can guess at the current, which of course in those days would not be measured, as there were no ammeters; at any rate, it is not given. Fifteen ohms and 59 volts $= \frac{59}{15} =$ nearly 4 amperes. Probably it was 4 amperes, as that is about current for a 40-carcel arc. Then externally it gave $4 \times 50 = 200$ watts, and the two piles together 400 watts, or ½ horse-power on 22 lbs. of coke per hour—not a bad result, considering the design and construction. The great length of the elements, the useless conduction of heat by

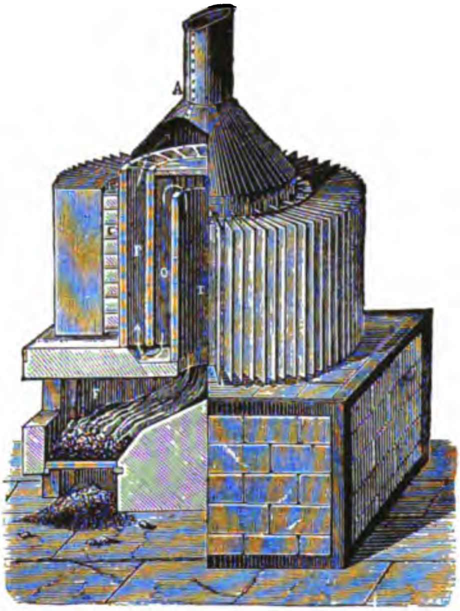


FIG. 76.—Clammond's Thermopile

the iron connectors, the high resistance, were all against economy. The total energy converted would be 109 × 4 or 436 watts in each pile, or 872 in the two piles. This pile is the only example of an attempt to work beyond the toys made by opticians, usually made up of bismuth and antimony bars of a length many times their section. These little piles should be made of very short lengths of bars about $\frac{1}{4}$ inch long, $\frac{1}{8}$ inch square section, the bismuth bars copper-plated on each end, and joined by copper foil strips soldered across, as shown in Fig. 72, to antimony bars, or, better still, Clammond bars about the same size. In this way a much better result is obtained. The galvanometer used with it should be of the same internal resistance.

The facts regarding thermo-electric elements are best shown by a diagram: the verticals indicating the power in micro-volts per degree, lead being taken as zero; the horizontals showing the temperature; and the slope of the lines showing the rise or fall in power as the temperature rises.

The following table shows the powers of different metals with constants + or – for calculating out the powers at different temperatures. It may be of some use, but it will be observed there are no data given for any practically useful thermo-electric materials, and none are to be found:—

	Temperature Range, C.	Thermo-Electric Values at t °C. in Micro-volts.
Nickel	250 to 310	$84.49 - .241t$
"	0 " 175	$22.04 + .0512t$
"	340 " 416	$3.07 + .0512t$
German silver	0 " 175	$12.07 + .0512t$
Soft platinum	– 18 " 416	$0.61 + .011t$
Lead		
Copper	– 18 " 416	$-\ 1.36 - .0095t$
Silver	– 18 " 416	$-\ 2.14 - .015t$
Zinc	– 18 " 373	$-\ 2.34 - .024t$
Hard platinum . . .	– 18 " 416	$-\ 2.6 + .0075t$
Steel	– 18 " 416	$-11.39 + .0328t$
Iron	– 18 " 416	$-17.34 + .0487t$

t is the mean of the temperatures of the hot and cold junctions in degrees Centigrade.

EXAMPLE:—Required the electromotive force of an iron and copper couple, the temperatures of the junctions being 0° C. and 100° C.

Iron	$-17.34 + .0487t$
Copper	$-\ 1.36 - .0095t$
Iron above copper . . .	$-15.98 - .0582t$

∴ Electromotive force per degree is

$$.15.98 - (.0582 \times 50) = 13.07.$$

∴ Electromotive force of the couple is

$$13.07\ (100 - c) = 1307 \text{ micro-volts.}$$

Thermo-Electric Energy

The thermopile has never been properly treated by practical engineers. It resembles the steam-engine very closely from a thermo-dynamic point of view, and we cannot hope to make it highly efficient any more than we can hope for a highly efficient steam-engine; in both the great bulk of the heat, perhaps 90 per cent. of it, must escape conversion; in the steam-engine it escapes up the chimney, and by conduction and radiation, but the larger portion is rejected in the exhaust steam. We have no exhaust in a thermopile, but we have its counterpart in the heat escaping from the hot to the cold ends of the elements, and, as in the steam-engine, great attention must be paid to the cooling of the pile. Cold water for condensing in a steam-engine is of immense value, so is it in a thermopile; plenty of cold water for cooling the cold ends is necessary, and the quantity required rather more than that required for a steam plant of equal power; in fact the cooling is of more import than heating. In making practicable thermo-electric generators the design must provide for the continual washing of the cold ends by a sufficient volume of cold water to reduce these ends to a constant temperature little above that of the atmosphere. But, finally, it is not to be forgotten that electricity produced by the present mechanical means from fuel, is, although cheap, a very small fraction of the energy of the fuel, and obtained only by very complicated, expensive, highly depreciative machinery; probably no more than 10 per cent. of the full energy appears as electrical energy at the terminals of the dynamo-electric machine, with all the intricate refinements. When Watt found the steam-engine, its efficiency was no better, if as good, as the present-day thermo-electric generator, yet it was doing good work. And an eminent scientist proved conclusively by the data then known regarding steam-engines that no ship could ever cross the Atlantic Ocean by steam-power, for it could not carry enough coal, even when completely filled up with coal without any cargo. And about twenty years ago another eminent scientist declared that the thermopiles would not exceed an efficiency of 6 per cent., and proved it by mathematics. In the first instance, no doubt, the statement was the truth, *at the time it was made;* perhaps the same may be said of the second case. At present 5 per cent. is about the best efficiency obtained by the thermo-electric generator, and that of the Cox type, using a cooling water-jacket. But much better results are theoretically certain of attainment by attending to the various points put forward in this chapter.

The subject has much interest, and the more so when we consider that any kind of fuel may be consumed in a thermopile, gaseous liquid or solid, and that there are no moving parts, except what might be required to feed in the fuel and circulate the cooling water.

Gas Electric Generators

The Gas Battery.—Mr. Grove succeeded in obtaining a continuous current from a battery in which the active elements were gases (*Phil. Mag.*, Dec. 1842; *Phil. Trans.*, part ii. 1843, and part ii. 1845). It consisted originally of a series of fifty pairs of platinised platinum plates, each about a quarter of an inch wide, enclosed in tubes partially filled alternately with oxygen and hydrogen gases. The liquid in the tubes was dilute sulphuric acid (sp. gr. 1.2), and the following effects were produced:—

Oxygen and olefiant gas . . .	. Very feeble, but continuous.
Oxygen and carbonic oxide . .	Notable effects. Slight symptoms of decomposing water.
Oxygen and chlorine . . .	Considerable action at first, scarcely perceptible in 24 hours.
Chlorine and dilute sulphuric acid	. About the same.
Chlorine and hydrogen . . .	Powerful effects. Two cells decomposing water.
Chlorine and carbonic oxide .	. Good. Ten cells decomposing water.
Chlorine and olefiant gas . .	. Feeble.

With respect to the theory of the gas battery, Mr. Grove remarks:—

"Applying the theory of Grotthus to the gas battery, we may suppose that, when the circuit is completed at each point of contact of oxygen, water, and platinum in the oxygen tube, a molecule of hydrogen leaves its associated molecule of oxygen to unite with one of the free gas; the oxygen thus thrown off unites with the hydrogen of the adjoining molecule of water, and so on, until the last molecule of oxygen unites with a molecule of the free hydrogen: or the action may conversely be assumed to commence in the tube containing the hydrogen."

The form of gas battery employed by Mr. Grove in his later experiments is shown in Fig. 77. In this arrangement oxygen and deutoxide of nitrogen gave a continuous current; and a permanent deflection of the galvanometer was produced when a piece of phosphorus was suspended in one of the tubes filled with nitrogen.

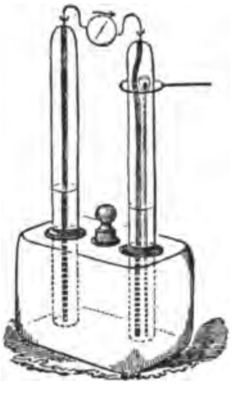


FIG. 77.—Grove's Gas Battery

This subject has not been fully exhausted, for it is not proved yet where the chemical action takes place, whether on the strip as it is supposed, or on the liquid surface, or only at their junction.

About twenty years ago a Mr. Kendall produced a pyro-electric generator. He observed that a current passed between two tubes separated from each other by a vitreous substance like glass which was heated to the melting-point, hydrogen being passed into the inner tube. The action is probably due to electrolysis of the vitreous substance and the combination of the hydrogen which transfuses through platinum and other metals at a red heat. Others have made pyro-electric batteries of fused glass or other electrolytes at high temperatures into which iron and copper electrodes were immersed. It might be possible in this way with the aid of heat to produce electrical energy from gaseous fuel and a direct process, but the subject is obscure and nothing practical has been brought out.

The energy in one pound of coal is thus calculated: Take one pound of Welsh coal having 15,000 thermal units, equal to 12,000,000 foot-pounds. Now a good engine and boiler give $\frac{1}{2}$ horse-power for one pound of coal = 1,000,000 foot-pounds of work, that is, using $\frac{1}{12}$th of the energy. But this is, under ideal conditions, rarely possible in practice. It is sometimes reached on steamships, but only on specially-arranged trials. The highest efficiency in practice is under 10 per cent. If we deduct everything, such as power for pumps, fans, economisers, coolers, stokers, and so on, probably 7 per cent. is nearer common practice with the best of plant, and for small engines 1 per cent. is not uncommon efficiency.

No steam-engine can exceed in thermo-dynamic efficiency the ratio—

$$\frac{\text{(Boiler Temp.)—(Condenser Temp.)}}{\text{Boiler Temp.}},$$

and this, with the best practical engines, is only about 0.3. The Diesel gas-engine and dynamo combined seems at present the cheapest and most efficient electrical generator from fuel, using, as it does, cheap fuel of high calorific value.

At the present rate of coal consumption in steam-engine plants, the supply of cheap coal is fast running down at an accelerating pace, and as it is the chief raw material of British industry in towns and cities, unless some improved means of obtaining mechanical and electrical energy are adopted, many of the manufacturing industries must perish within the next hundred years. To this great waste of coal the thermopile may not make much towards diminishing it, but it is a possible method for utilising heat.

In the ideal generator of electricity from fuel there should, of course, be no heat at all; the energy should pass directly into electrical energy as it does in a primary voltaic cell.

Carbon is not an ion. Neither can we use oil; but gases can and have been used in primary cells, such as Grove's. This points to a hopeful direction for experiment, using atmospheric oxygen, and gaseous ions made from fuel.

The electric arc is the most striking heating effect of the electric current, and in the crater—that is, the hollow end of the positive electrode of an arc produced by continuous current—we have the highest temperature on earth, said to be about 3500° to 4000° C. The arc for lighting purposes is produced in every case by passing current between carbon rods held about $\frac{3}{16}$ to $\frac{1}{4}$ inch apart; after the arc is struck, the points very soon assume the form shown in Fig. 78, when the arc burns in air. The conical shape is formed by combustion with the oxygen of the air, and the little melted globules to be seen are impurities melted by the high temperature. They fall off as ashes later on.

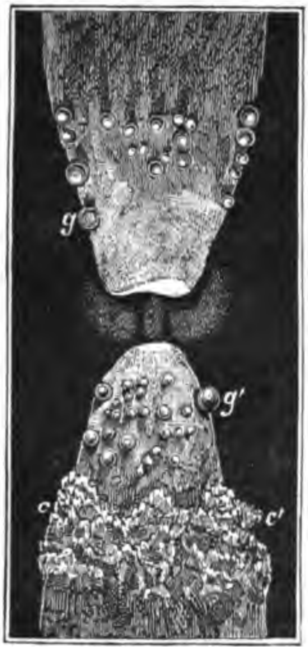


FIG. 78.—Carbon Points of Arc Lamp Burning in Air

The arc burning in the open air is limited in length to about $\frac{3}{8}$th inch, and to a difference of potential of about 45 volts across the arc. If its length is further increased, and the potential also increased, its "flame" gives less light with a great deal of heat.

By burning the arc in a vacuum or in an atmosphere of inert gases, the arc can be made longer, and a much higher P.D. used, up to even 200 volts, giving a long thin arc; and the consumption of carbon is very much lessened as the coning effect does not take place, the carbon ends remaining nearly flat as shown in Fig. 79. Owing to this longer arc and flatter ends, the enclosed arc, as it is called, is much better as an illuminant than the open, and does not require refilling with carbon oftener than once in a hundred hours.

Against these advantages there are the drawbacks:—

(1) The arc must be enclosed in a small air-tight globe of clear glass, and this again in a ground glass or opal glass globe to diffuse the light and cut off the violet rays. Thus about half the light is cut off.

(2) The arc not being confined to a crater wanders over the flat carbon ends, causing a shifting of the light.

(3) The ashes formed adhere to the small globe and still further cut off the light.

The burning of arcs in vacuum or inert gas was studied fifty years ago by Wiedman and Davy, and so also was the effect of adding salt to the carbons. Casselmann found that he could double the length of an arc by soaking it in a potassium solution, and drying it before use.

This effect has been frequently adopted by inventors. Cored carbons made with a soft core were introduced to maintain a central crater. A core of pure silica (fine white sand) lengthens and steadies large current arcs wonderfully.

Joblochkoff and Jamin introduced electric candle arc lamps. That is, the carbons were placed parallel side by side and burned down like a candle.

Jamin, in order to burn the candle from the bottom upwards, so that the bulk of the light would be thrown downwards, provided an electro-magnetic field to repel the arc and keep it at the lower end.

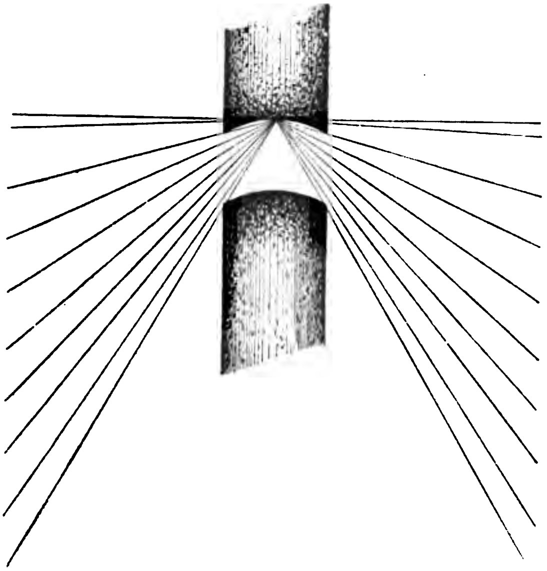


FIG. 79.—Carbon Points of Arc Lamp Burning in a Vacuum

Recently these old ideas have been revived, and the enclosed arc has become quite popular, especially for alternating circuits.

The candle form inverted, and with the arc maintained at the lower end, has been reintroduced by Bremer, who also adds salts to the carbon to produce a larger arc, and uses an electro-magnetic field to repel the arc to the lower end. It gives a large flaming arc of orange tinge.

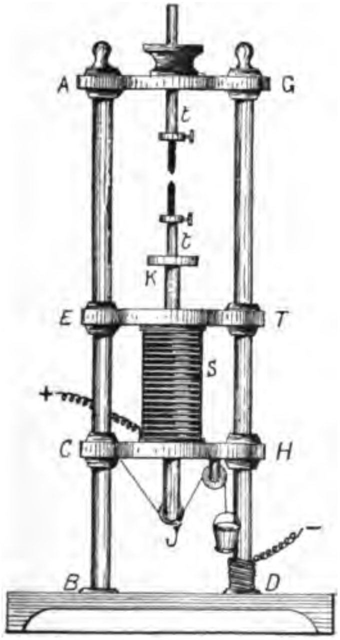


FIG. 80.—Archerau's Arc Lamp

Regulators for arc lamps we have already discussed in Vol. I. Reference may, however, be again made to one of the first and simplest type of arc lamps invented by Archerau in 1848. It makes an excellent lamp even now compared with some modern ones, and as it is easily made by students and may be useful, it is shown in Fig. 80. The solenoid should be about 5 inches, and the core about 8 inches long. The inside diameter of the solenoid is 1 inch, wound with No. 12 cotton-covered wire in five layers. The core should be tapered soft iron *à la Pilsen* core, and should be carried in a brass tube. The core is $\frac{3}{4}$ inch diameter at top end, and tapered down to $\frac{3}{16}$ inch at bottom. Little guide wheels, top and bottom, guide the brass tube, which at the top carries the negative carbon.

The carbon and the tube containing the core are balanced by a cord and weight as shown in the figures. This weight may be hollow in order to add shot to adjust the arc to the proper length. If the weight is too small, the arc will pull too long, and flame. If the weight is too great, the arc will be too short, and it will hiss.

On a continuous current of 65 volts, and with a resistance of 1.5 ohms, it will work very well. It is but a short step from this old lamp to many of to-day. As shown, it would do very well for inverted lamps. The inverted lamp is used to diffuse the light from the arc by throwing the light upon a white ceiling or disc, from which it is scattered downwards. It is shown in Fig. 81 in this fashion.

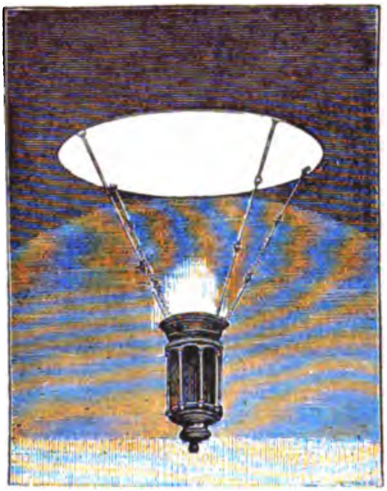


FIG. 81.—Inverted Arc Lamp

Arc lights are run often in series order. It is, therefore, necessary to have an automatic cut-out, in which a resistance is substituted for the arc, in case the mechanism sticks and hangs up the carbons. The cut-out shown in Fig. 82 is a modification of one of Varley's. The diagram indicates clearly the electrical connections. About the coil of the magnet are wound a few convolutions of insulated German-silver wire, which are included in the shunt circuit. The current in this supplementary coil flows in the same direction as in the main coil, and the object of the supplementary coil is to cause the electromagnet to act more quickly to open the shunt circuit when the lamp is lighted. The resistance of the shunt coil is very slight (about

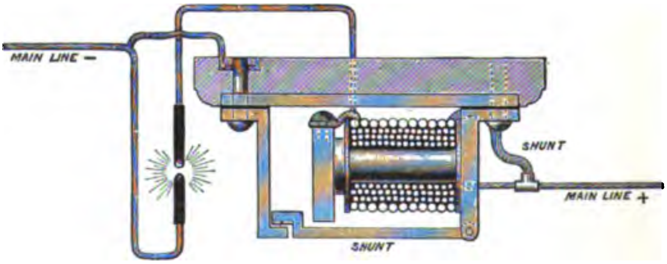


FIG. 82.—Automatic Arc Lamp Cut-out

the same as that of the lamp with the carbons in contact), and, with the shunt closed, and the lamp circuit open, it is obvious that the entire current must pass through the resistance, but there being few convolutions, and these at a distance from the core of the magnet, too little magnetism is developed to lift the armature. Whenever the lamp circuit is closed, however, the current at first divides between the two coils on the magnet, and both co-operating, lift the armature very quickly. As soon as the armature is lifted the shunt is broken, and the entire current passes through the lamp.

Arc lamp mechanisms do not come in here for description; they are exceedingly numerous, and many are very intricate and interesting. They are fully described in special works on arc lamps, and those engineers interested in them should consult some of these works. In all of them the arc is the same, and the mechanism designed to strike the arc apart and feed the carbons together at the rate they burn away, so as to maintain them at a constant distance apart.

CHAPTER IV

ELECTROLYTIC, MINING, AND TRACTION INSTALLATIONS

Electrolytic installations comprise installations for cold electrolysis and high temperature electrolysis, the refining of metals, extraction of metals from ores, production of chemicals, gases, and liquids, the separation of elements and the combination of elements.

These installations are rapidly growing of more and more industrial importance, and the cheap gas or oil engine-power is likely to give them a still greater impetus.

Unfortunately electrical engineers are seldom chemists, and chemists are as seldom electricians; hence the subject has not been thoroughly considered from practical points of view.

Take the generators in use, excluding water power, these in most cases are simply electric-light dynamos directly connected to steam-engines, producing electrical energy at about the same rate of cost as that found in electric-light installations.

In some cases the products are of sufficient value to cover this high cost for energy, but in the majority of cases they are not.

Now electrical energy for chemical purposes does not require to be so strictly steady in pressure and well regulated as for lighting; so that neither so expensive engines nor dynamos are necessary, and the very cheapest of cheap fuel must be used.

If the fuel gas made from cheap slack, by the Mond or other process, is available, then large gas-engines at moderate speeds may be used; but it would be folly to attempt direct coupling of the engines and dynamos, for the slow-speed dynamos would cost dear, and offer not the slightest advantages over belt or rope driven high-speed machines.

The Diesel type of oil-engine, working at $\frac{1}{10}$th of a penny per brake hour per horse-power, offers another cheap source of energy, but it is also too slow for direct coupling to moderate-speed dynamos.

Direct coupling may be tolerated on a steam turbine, but steam is not now able to compete with cheap gas and oil engines for this purpose.

Industrial electrolytic work, like many other industries, cannot nowadays be set up without very careful considerations as to the suitability of the site. Cheap fuel, or cheap power, or cheap electrical energy, delivered at the works, is a first necessity. The next is the facilities for carriage of raw materials and finished products, bearing in mind that finished goods will bear more carriage expenses than raw materials. As a rule, little skilled labour is required, so that question is not of much importance.

There are two systems of working—first, the low-pressure system, using large vats in parallel connection, the second using small vats in series connection. The first system is more costly at first, but much safer and more economical to work. Each vat may be treated quite independently. There is little loss by leakage, and the insulation of vats, switches, leads, &c., is not difficult. It requires, however, large conductors and good junctions; but these may be reduced to a minimum by good designing of buildings and arrangement of the plant. The generator should be central, with the vats arranged all around, so that none of the work is far from the generator.

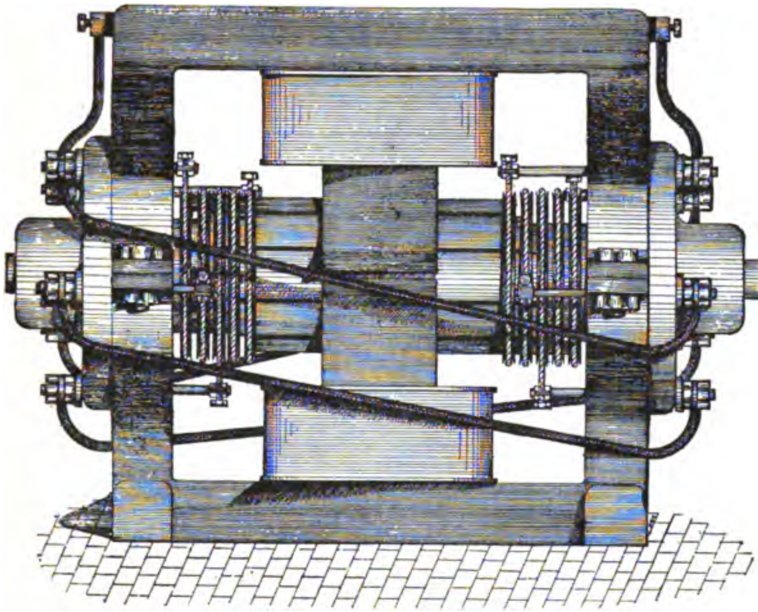


FIG. 83—Homopolar Dynamo for Large Currents

There is only one kind of dynamo for this low-pressure work, far better than all others, and that is the homopolar machine, shown in its latest form as designed by the author in Fig. 83. In this machine there are five conductors in series in the armature, connected to collecting rings, from which the current is collected by brushes or copper strip. At a speed of 1000, this machine, with a pole tunnel of 12 × 10 inches, gives 2000 amperes at 10 volts. There is no commutator whatever, no adjustments required; it will run for years without attention.

Another modification of this machine was described in Vol. III. of this book, for higher pressures for working in series.

Compare this machine with the type of machine usually employed, shown in Fig. 84. Here we have the old multipolar field-magnet, with an armature of laminated iron carrying a complicated elaborate winding of very heavy insulated copper cable or bars; and these windings coupled either to a commutator of great diameter, to accommodate very large brush collecting and commutating, or two smaller commutators working in parallel, as shown in Fig. 84. This style of machine is, therefore, very expensive to begin with, and requires much attention always to secure good contact and commutation of the brushes.

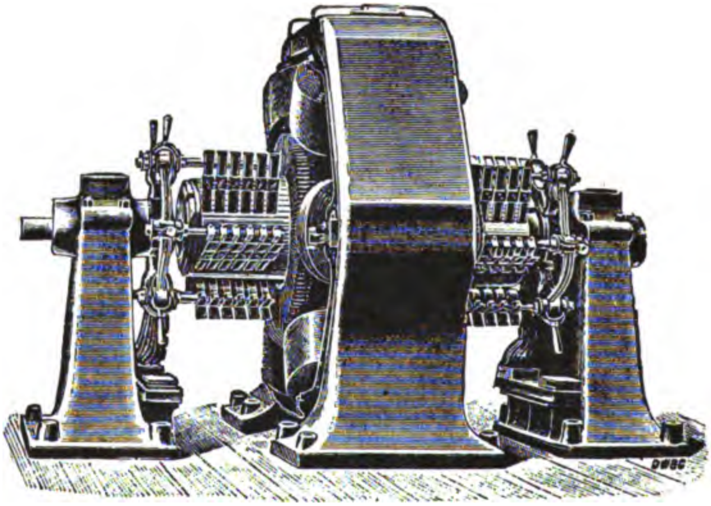


Fig. 84.—Multipolar Dynamo for Large Currents

It is worthy of note that the first Homopolar Dynamo ever made by Siemens & Hahke, shown on page 166, Vol. I. of this work, was put to work at Oker twenty years ago on electrolytic refining of copper.

For all electrolytic work under 100 volts, the homopolar is the only machine for the work.

For parallel working the machine must be self-regulating compounded, and for series working naturally a series wound dynamo might be used for constant current, and the vats cut out by short-circuiting across a by-pass conductor.

The homopolar machine has the advantage also that different voltages may be had from it as desired by arranging the connecters of the bars on the armature.

Electrolytic Current Workings

The instruments and switches in this class of work are always of special make for the special work to be done; when working with low pressures from 0.5 to 5 or 6 volts, and currents from 100 to 10,000 amperes. No ordinary electric light affairs are of any use. Volt-meters present no difficulty, and one should be connected across each vat. Knowing what current may be expected to pass into each vat, an ammeter reading correct for some distance on either side of this normal current should be in series with each vat.

Perhaps the most suitable ampere gauge would be the Kelvin type shown in Fig. 85, as it is made with very low internal resistance (and might be easily made still lower in resistance), and with connecters for sweating on the leads.

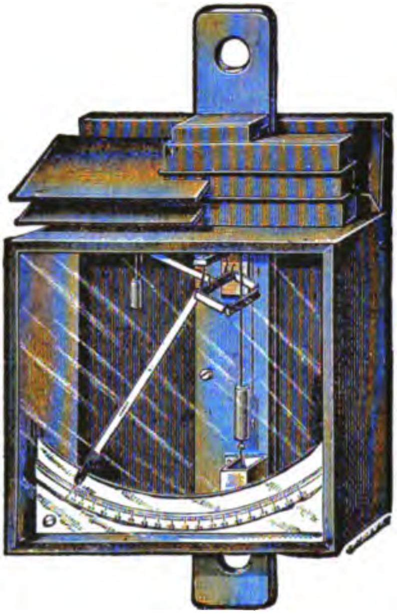


Fig. 85.—Ampere Gauge

As for switches, ordinary types are useless; the best and simplest switch for the purpose is a mercury cup switch, shown in Fig. 152, Vol. II. Using mercury, instead of a solution of salt, meets all requirements.

Whichever system is adopted, series or parallel, a voltmeter should be across each vat; if a series system is employed, one main ammeter may be used.

The series system, on the whole, has some advantages, if proper safeguards are made against leakage and poor insulation. Smaller vats easier got at and worked can be used, and more equal results obtained, so that for ordinary processes about 60 volts or 65 volts would be found most useful.

Many fused minerals and salts can be electrolysed, and their elements separated at high temperatures. For these installations higher pressures are necessary. Thus alumina dissolved in a bath of molten cryolite is separated and aluminum obtained. Each crucible requires about 20 volts for this process.

For chemical electric effects on gases much higher pressures are necessary—from 15,000 to 1,000,000 volts—in order to produce ozone or nitric acid from air.

The Atmospheric Products Co. of Niagara have worked out the process for obtaining nitric acid on the principles described in Vol. I. of this book, p. 162. Their process is described as follows:—

In the experimental station a 45-K.W. generator, which ordinarily delivers 0.75 ampere direct current at 8000 volts, but of a capacity to give several amperes at 15,000 volts, has been in use. The company has found it necessary, in order to secure efficiency, to use an arc which is divided into small, thin, flat sub-divisions, so as to present a large surface for a small amount of power. In fact, the thinner the arc, the greater is said to be its efficiency up to the point where it is broken. There are 138 of these arc contacts, and each is made and broken 50 times per second, each arc receiving about 0.005 ampere. Despite the number of the arcs, they are all sprung successfully, 6900 in the apparatus in use, each arc lasting about $\frac{1}{20,000}$th of a second. When the arcs form there is a sudden increase in the current, and short-circuiting is prevented by inductance coils in series with the arcs. These retard the current for about $\frac{1}{40,000}$th of a second, and during the remainder of the period, or another $\frac{1}{40,000}$th of a second, as the arc is drawn out and about to break, their effect is to prolong the arc. When 8000 volts are used, with an average of $\frac{1}{200}$th of an ampere to an arc, the arcs are drawn out 4 to 6 inches.

The apparatus is of iron, standing 5 feet high, and is 4 feet in diameter. Attached to the sides there are six rows of inlet wires, twenty-three to a row. A vertical shaft runs through the centre, and contains a series of twenty-three radial arms. Each plane has six radial arms. The radial arms are tipped with platinum wires that extend to within $\frac{1}{20}$th inch of the similar wires on the opposite poles. When the two points get close a spark leaps about $\frac{1}{8}$th inch to meet the approaching point, and as the point retreats the arc is drawn out. In series with each arc is a resistance coil 12 inches long and 5 inches in diameter, immersed in oil, and containing several thousand turns of wire.

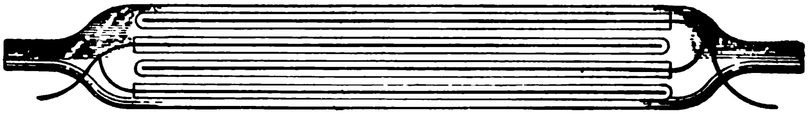


FIG. 86.—Ozoniser

The gaseous ozone producing plant requires still higher E.M.F. sufficient to produce the silent discharge from points through the air, or by passing oxygen or air between the poles of a high-pressure generator, as in Siemens' Ozoniser.

Fig. 86 is an ozonising arrangement to be used with an induction coil; eight or ten pairs of tubes made of very thin glass are connected with the terminals in the manner shown. The whole are surrounded by a long glass cylinder, through which oxygen or air is slowly passed. The amount of ozone is increased if the outer tube be surrounded with water.

Ozone may also be produced by electrolysis at low pressure, as follows:—

Andrews' apparatus for obtaining ozone by electrolysis is shown in Fig. 87. The most convenient liquid for the purpose is a mixture of 1 pint of sulphuric acid and 6 or 8 pints of water; and the lower the temperature at which the electrolyte in maintained during the process, the greater is the amount of ozone. The glass bell-jar, *A*, is open below, and contracted to a neck above, into which a bent connecting tube is fused. This bell-jar is suspended in a round cell, *B*, *B′*, of porous earthenware, leaving a clear space of 2 inches between its lower edge and the bottom of the porous cell. The whole is placed in a glass jar, *C*, *C′*, of somewhat larger dimensions than the cell; a bundle of platinum wires, *P*, suspended below the bell-jar, acts as the positive pole, and a broad ribbon of platinum, *N*, *N′*, placed between the outer glass jar and the porous cell, as the negative pole of a battery of 8 or 10 volts.

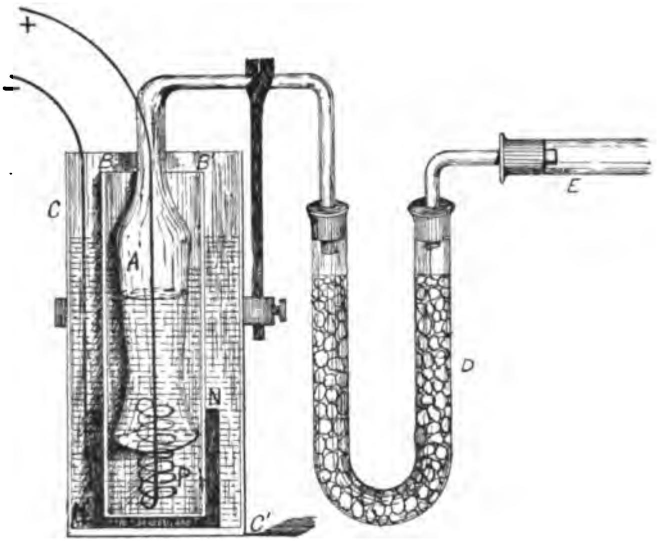


FIG. 87.—Ozone Producer

From the bell-jar the mixture of ozone and oxygen disengaged at the positive pole passes to a sulphuric drying tube, *D*, from whence it is stored or used.

The subject of solutions, vats, chemical reactions, and processes involved, are fully treated in works on Electro-Chemistry, and do not come within the scope of this work.

Mining Installation.—Electrical transmission of power in mines has long been successfully used for pumping, haulage, coal-cutting, and lighting underground; and at the pit-head for driving saws, fans, coal-screening and coal-washing machinery. It has not been much used for winding up the shaft, although it would no doubt perform that work well: it is doubtful if it could do it better than the steam-engine direct. As a rule the boilers and main winding engines are contiguous, and the power has not to be transmitted, for the winding drums are on the engine bed, yet some "cranks" would advise the use of an electric motor in such a case as this. If, however, the whole power for a mine were electrical, delivered from a cheap source, then, of course, the winding and all other work would be of necessity by electro-motors.

In all other operations about a mine, the machinery is usually scattered all around at some distance apart, some a mile or so away below, hence the utility of electricity in transmitting power to the several machines.

Simplicity is the first consideration in mining engineering: all the work is hard and rough and under the rudest conditions. Any complicated system requiring highly-skilled attendance and great care cannot be entertained; efficiency is not of so much account as reliability, safety, and durability. The driving of fixed machinery such as coal washers and screeners, saw-mill, engineers' shop, pumps, &c., at the pit-head are easy problems. So also is the pump-driving at the bottom of a shaft, and the electric lighting of the main underground roads. The difficulties begin when the driving of machines at the working coal faces is tackled: these are far from the pit bottom, and always shifting farther off daily.

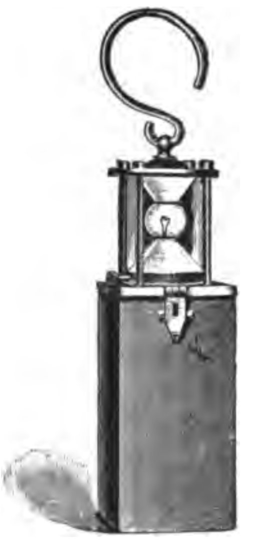


Fig. 88.—Sussmann Lamp

Many attempts have been made to produce an electric miner's lamp for working at the coal-face, but without much success; the only possible electric supply in such a position is the storage cell, and that is too expensive and troublesome, and heavy. The best lamp yet made is the Sussmann; the battery is a semi-fluid storage battery, and has a capacity sufficient for ten hours' running of a one candle lamp, and takes eight to ten hours to charge; its weight, about 4 lbs., is rather against it. The lamp for a miner has to fulfil some difficult conditions: it must be strong, capable of withstanding rough usage, upsetting, or dropping; be of small weight, not over 1½ lb., burn for twelve hours on end, and be cheap to purchase and maintain in order. Fig. 88 represents the Sussmann miner's lamp. The battery is in the bottom compartment and the lamp between a biconical silvered reflector.

In the main roads lamps of 16 C. P. are used in watertight thick globes: these are quite safe even in fiery mines, for any damage which might break the globe or fitting would instantly shatter the lamp filament. The switches should be few, and also water-tight. The real danger is the breaking of wires and cables, or short circuits: these accidents would result in a flash which would fire any combustible. Perhaps the safest and best system is the Mavor & Coulson C. C. system, with iron wire armouring on the cables, with cast-iron-switch and fuse boxes, as described in Vol. II. of this book. As to the electric pressures to be used, it may be at once recognised that all pressures over 100 volts are dangerous, especially to men in wet or damp places; that being so, and pressures much above 100 volts being desirable, we must admit the danger and minimise it by thoroughly good insulation, and protection from contacts. It is folly to preach that a healthy man will stand 500 volts, as some do, even in the face of the fact that many deaths have happened on 200 volts and less.

It is not the pressure which kills, it is the current; and if the body, healthy or not healthy, makes a contact under conditions such that a current exceeding 0.25 amperes passes into the body, death is the result, no matter what the pressure may be. Some subjects have dry, highly-resisting skins, and some are thick-skinned. These of course withstand higher pressures than others. Thin, moist-skinned subjects have very low electric resistances. It is therefore no proof that 500 volts is safe, to state that some people have made contact therewith without being hurt. It is not a question of health and strength at all, for some very powerful, healthy men have a very low resistance, especially when perspiring; and other weak people have sometimes a very high resistance electrically speaking.

From these considerations it must be evident that only the most carefully planned and carried out wiring is admissible, with every precaution for safety.

At the pit-head the wiring is best carried out on overhead insulators fixed to poles and buildings, bare hard brown copper wires being used with efficient lightning protectors, as described in Vol. II.

We may now refer to the special electrically-operated machines, beginning with coal-cutting and drilling machines working at the face. In this position there is great danger of fire in fiery mines, so that electricity has been mostly confined, for working at the coal face, to mines where there is no gas, where naked lights can be used.

Coal-cutting machines are of three types—the bar-cutter, the wheel-cutter, and chain-cutter. The first two have been mostly used in Britain, the last to some extent in American deep seams.

Electrical Compressed Air-Pump

Compressed air has been generally used for transmitting power, and has the merit of safety from fire and assisting ventilation. It has serious drawbacks in mines, for reheating is not possible before using the air. It has, however, been proposed to use the air-engine at the face, and to drive it from an electric motor and air-pump situated in a safe place near the working face. A combined pump and motor for this purpose is shown in Fig. 89 as made by the B.T.H. Company.

The best results, however, are obtained by working electric coal-cutters direct where possible. We shall proceed to give Messrs. Mavor & Coulson's bar-cutter full notice, as it is one well designed for the work, and we can agree with most of the claims made for it.

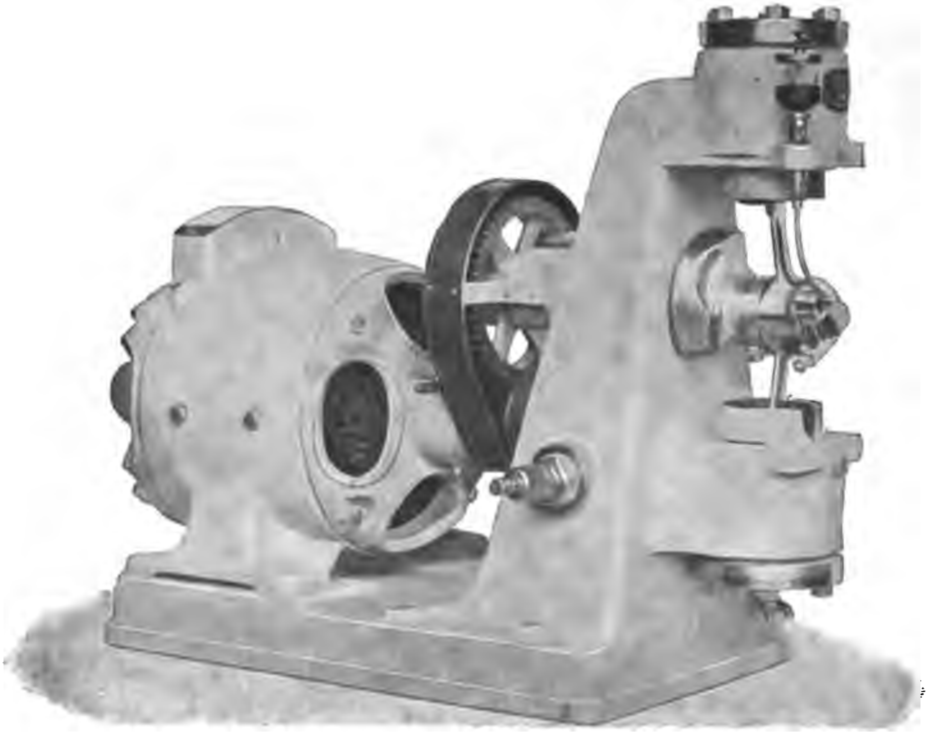


FIG. 89.—Motor-Driven Air-Pump

The capabilities of the coal-cutting machines now on the market, and their adaptability to widely-differing conditions of employment, entitle them to the most serious attention of mining engineers. There are many seams where mechanical working would be impracticable or unprofitable, but they are much fewer than is generally supposed.

The number of coal-cutting machines in use in Great Britain in the year 1900 was 311. In the United States, where the total output of coal is approximately the same as ours, there were 3125 machines. Of this number nearly 2000 have been set to work during the last five years, and the number is rapidly increasing. It is chiefly the lower cost of production by machine-cutting which has enabled American coal to successfully attack our export trade. But indications are not wanting in this country of an awakening of lively interest in machine-mining, and there is promise of an immediate and wide expansion of this method of winning coal.

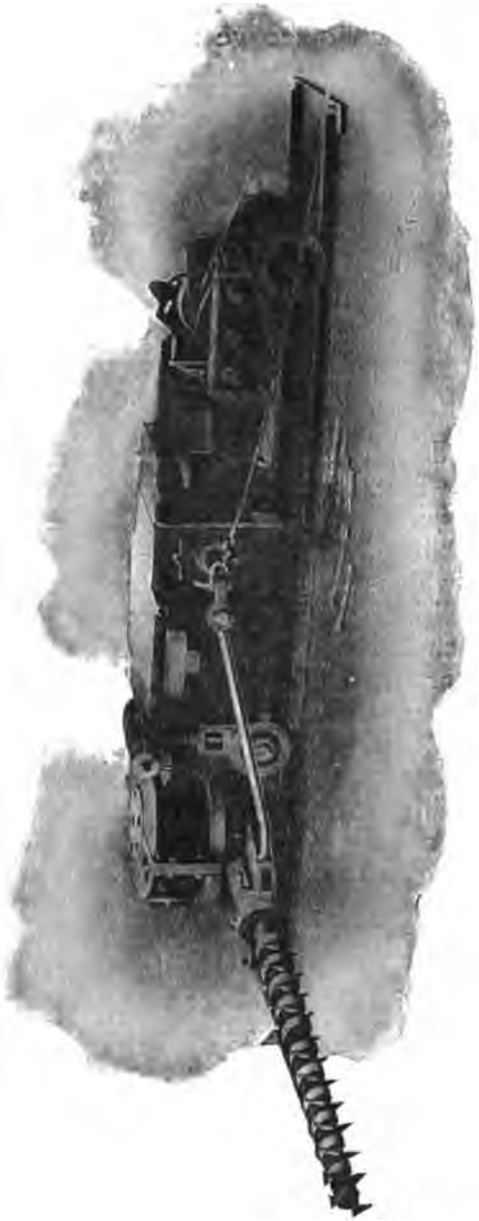


FIG. 90.—Bar Coal-Cutter

In thick seams the value of the coal-cutter in reducing the cost of production and increasing the output has now been abundantly demonstrated, and the number of machines in use is rapidly increasing. In medium seams also, especially where hard holing is encountered, the advantages of machine-cutting are leading to its more extended adoption. For working the thin seams, which are in many cases being perforce resorted to, there is no economical alternative to machine mining.

Mechanical coal-cutters have been in use in this country to a very limited extent for twenty-five years, but until recently they have been dependent upon compressed air for their motive power. To the inconvenience and low efficiency of this mode of transmitting power was partly due the slow progress of machine cutting. But the introduction of the electric motor to mining operations opened a new era for the coal-cutting machine, and the special advantages of the rotating bar when used in conjunction with the electric motor were recognised. Disfavour and disrepute were, however, brought upon the bar type by the premature efforts of its advocates to launch upon the market a machine which was crude in design and defective in construction. Criticisms which applied to the early bar machines have no reference to the machine here described, and shown in Fig. 90.

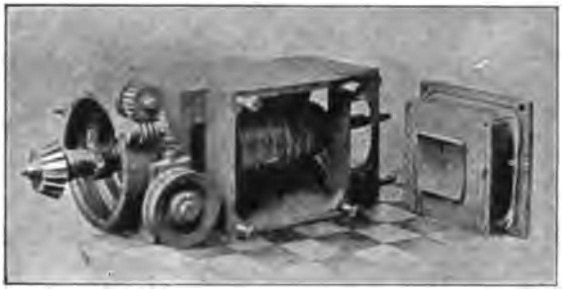


FIG. 91.—Motor for Coal-Cutter

In this coal-cutter many important improvements are embodied, and the defects and weaknesses of the earlier machines have been almost eliminated. The machine has practically been worked out at the coal-face, and has been perfected by careful modification in design.

The driving of a coal-cutter is probably the most severe duty to which an electric motor could be applied, but the exacting conditions have been recognised and met by a special design, which has resulted in immunity from breakdown. Apparently unimportant details have had careful attention; simplicity, strength, and convenience of handling being kept constantly in view.

The starting switch and resistance are enclosed in a gas-tight cast-iron box with insulated external handle. The switch, which has a quick and double break, is fitted with renewable contacts, and is of specially substantial build.

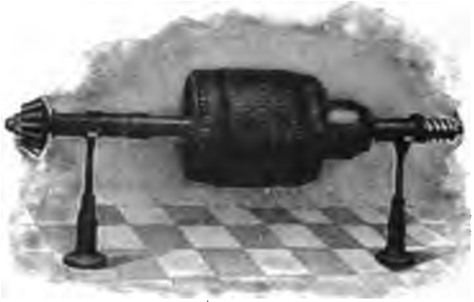


FIG. 92.—Armature of Motor for Coal-Cutter

The resistance coils are wound upon formers enclosed in a chamber behind the switch, and are readily accessible for inspection without disconnection or removal; in the same casting a tool-box is provided for the few tools which it is necessary to carry.

The motor, Fig. 91, is built to withstand the roughest treatment, and is so enclosed that it is absolutely gas-tight and effectually protected from dust and external damage. The shell is of high permeability cast-steel, and has incorporated with it the socket into which the spigot of the gear head is fitted, and also the hand gear by which the bar is raised and lowered. The pole pieces with their exciting coils are readily detachable from the sides of the shell, as shown on the illustration, so exposing the armature for inspection.

The armature, Fig. 92, is of the slotted core drum type, the core being built up on a cast-iron hub, which also carries the commutator independently of the shaft. Special care is devoted to the mechanical detail in the construction of the core and commutator, and in the winding of the conductors, to ensure that the completed armature shall be perfectly rigid and without the possibility of any relative movement of its parts. The armature as a whole is detachable from its shaft.

The brush gear is attached to the switch-box. The brushes have a fixed position, and are so arranged that they are easily removed for inspection, and the compensation for wear is automatic. A screw with external handle is provided to admit of such brush adjustment as is necessary being made without opening the hand hole.

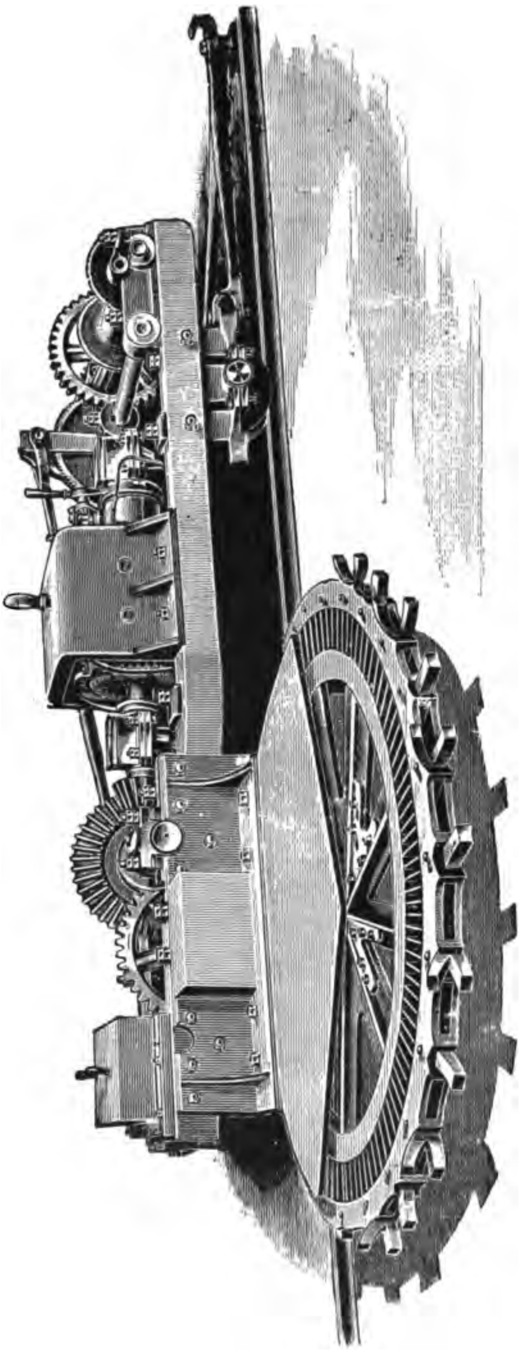


Fig. 93.—Disc or Wheel Coal-Cutter

It has been objected that the relatively high speed of rotation is a disadvantage of the bar as compared with the disc, and that the cutters may therefore be expected to wear more rapidly; also that the bar would not endure the strains put upon it, and would be subject to frequent bending or fracture.

The higher speed of the bar is a decided advantage in a machine to be electrically driven, as less gearing is required. Owing to the small diameter of the bar, the speed of the cutters is not greater than in the slower-running disc. Experience has proved doubts as to the strength of the bar to be without foundation. Many have been in use for years, without the occurrence of a broken or distorted bar.

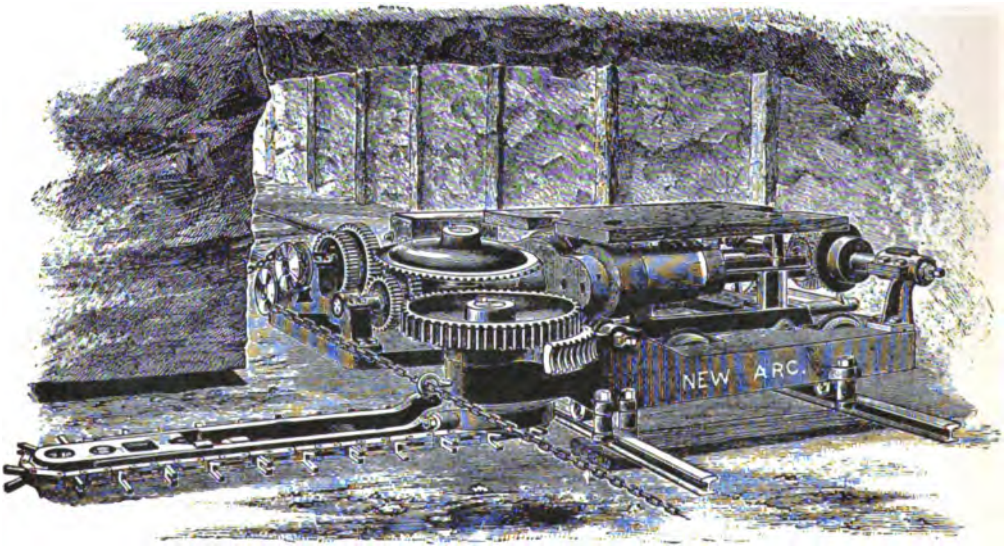


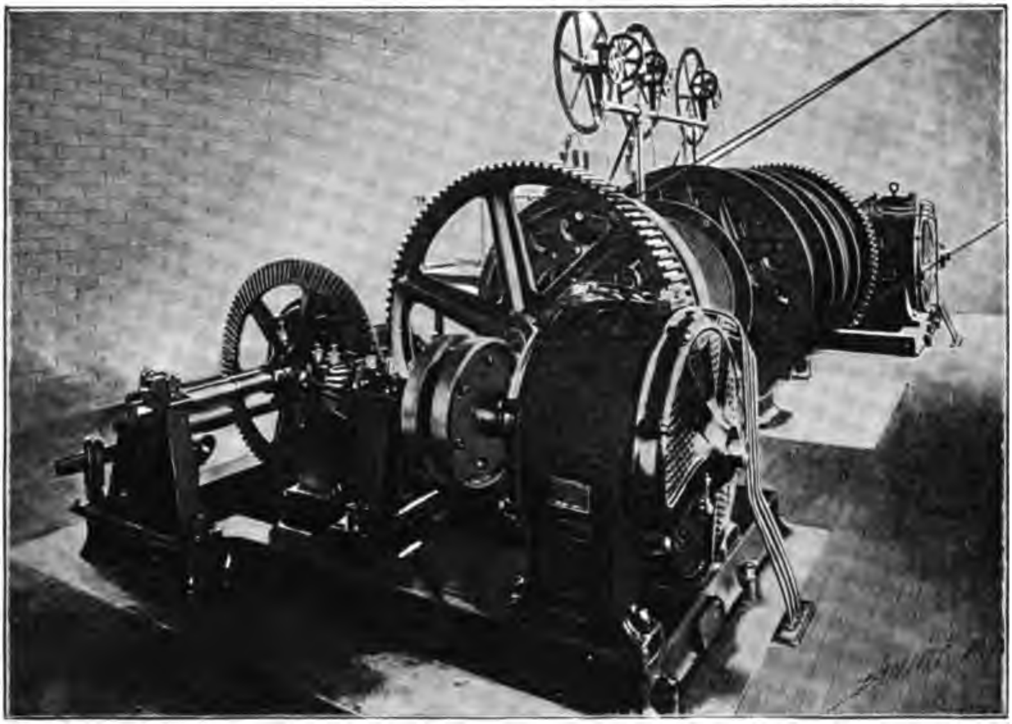
Fig. 94.—Chain Coal-Cutter

The wheel-cutter is shown in Fig. 93, as made by several firms; some of these have been made with wheels 7 feet diameter, taking 30 horse-power to work them. As a rule the power required is under-estimated and fluctuates a great deal, especially in the wheel machine. The speed of the cutters in both types of machines may be the same, but the bar machine cuts more regularly, and is not so readily jammed in the cutting.

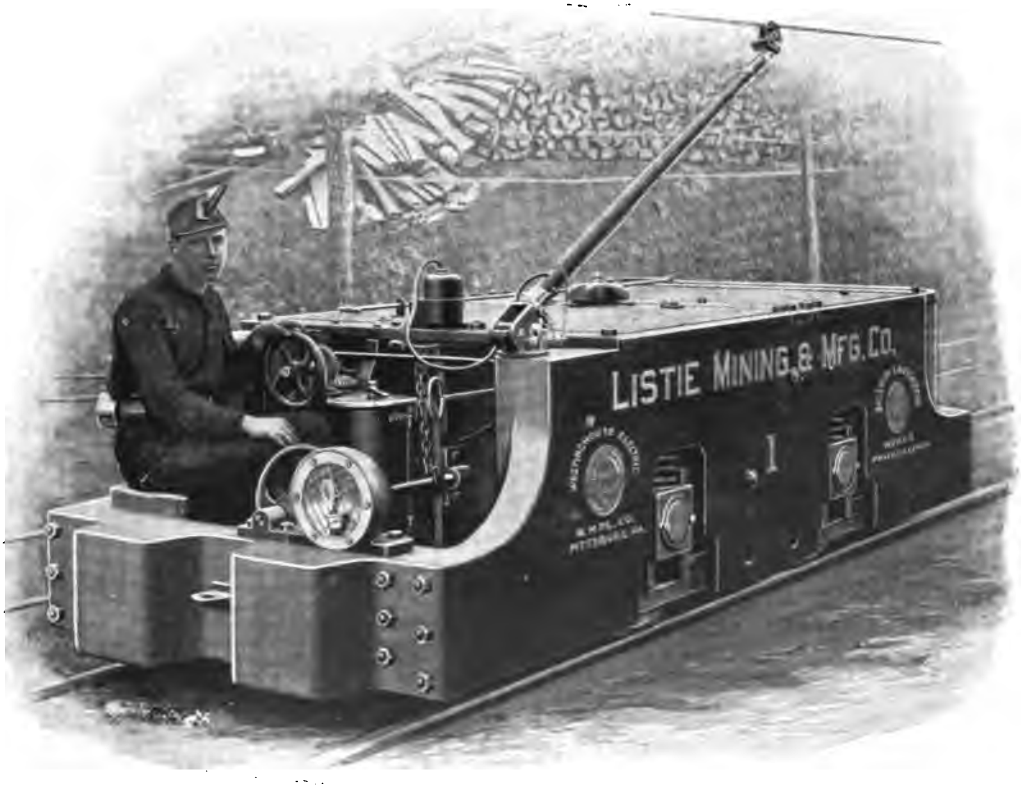
In the chain-cutter machine, Fig. 94, a long linked chain has cutters attached, as shown in the figure of an American coal-cutter. The chain is driven by sprocket wheel.

A 15 horse-power motor is required, 7 of which are absorbed by the cutters, the balance being absorbed in the mechanism and in hauling the cutters through the coal.

The arm carrying the chain cutters can be swung round along-



Electric Mining Haulage and Winding Machine



Electric Mining Locomotive

side of the machine to start the cut, and to enable it to be readily transferred from place to place; and the arm can be adjusted lengthways to take up the slack of the chain.

The average speed of cutting in coal is about 50 feet per hour.

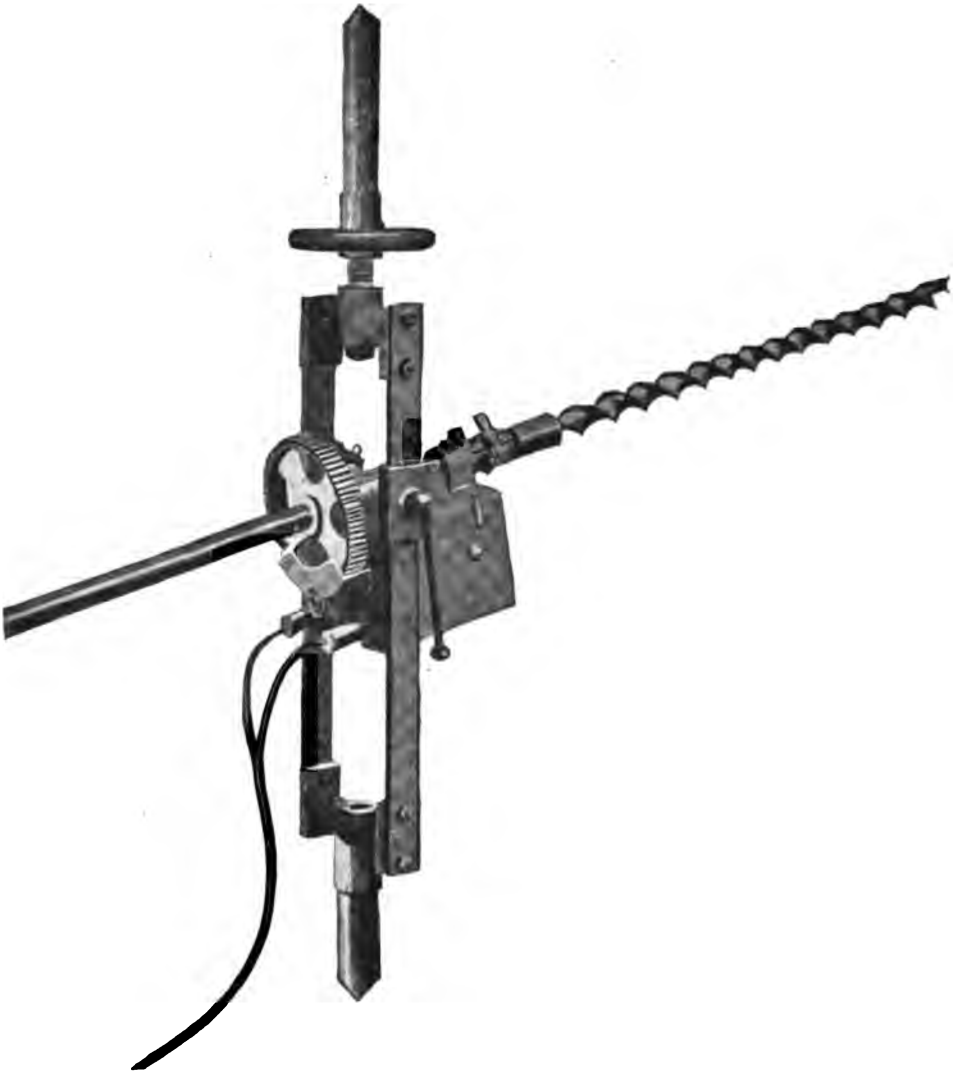


FIG. 95.—Coal Drill

Electric drills are mostly of the rotary type, no satisfactory percussive drill having been yet tried. This has been due entirely to faulty design of the magnets and solenoids employed. This can only be done by a skilled electrician, and is quite beyond the mechanical designer's powers.

Electric Drills

A rotary drill, shown in Fig. 95, consists of a steel auger or twist drill, operated by a small motor. This is a handy tool for driving headers, and is light in weight and takes up little room.

Rotating electric twist drills have given excellent results wherever they are applicable, which is, of course, only in the softer rocks, such as ironstone, salt, and coal. One of the best of these drills is that designed by Mr. A. L. Stevenson, Fig. 96, for use in the ironstone mines of the Cleveland district. It consists of a carriage supporting a standard, capable of being turned in any direction, which carries an arm, on one end of which is supported a small direct current motor, whilst the other end carries a twist drill driven by means of bevel gearing, the connection between the drill and its driving shaft being made by a Hooke joint, so as to allow the drill perfect freedom of motion. The drill is advanced automatically by means of differential gearing. Such a drill works at 220 volts, and requires 20 amperes, or, say, 6 horse-power at the drill. It makes 100 revolutions per minute, and drills in Cleveland ironstone at an average rate of 3 feet to 4 feet per minute; in a working shift of ten hours each drill will put in 100 holes, averaging 4 feet to 5 feet deep, in about eight different working places.

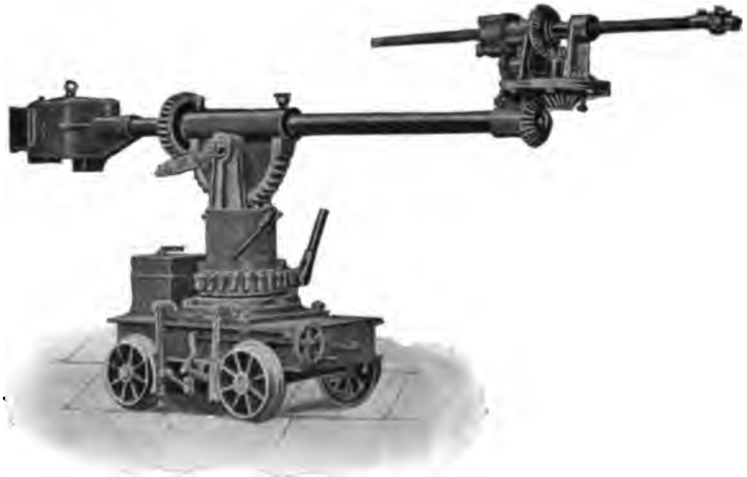


FIG. 96.—Stone Drill

Electric motors present quite special advantages for working diamond drills, and have been largely used for that purpose, both at the surface and for excavations underground. A drill making a 2-inch hole and bringing up a 1⅜-inch core, capable of drilling easily to a depth of 600 feet, can be driven by a 2¾ horse-power motor.

Magnetic Separators

The separation of magnetic from non-magnetic materials in mining operations is sometimes a most useful process, and very many machines have from time to time been invented.

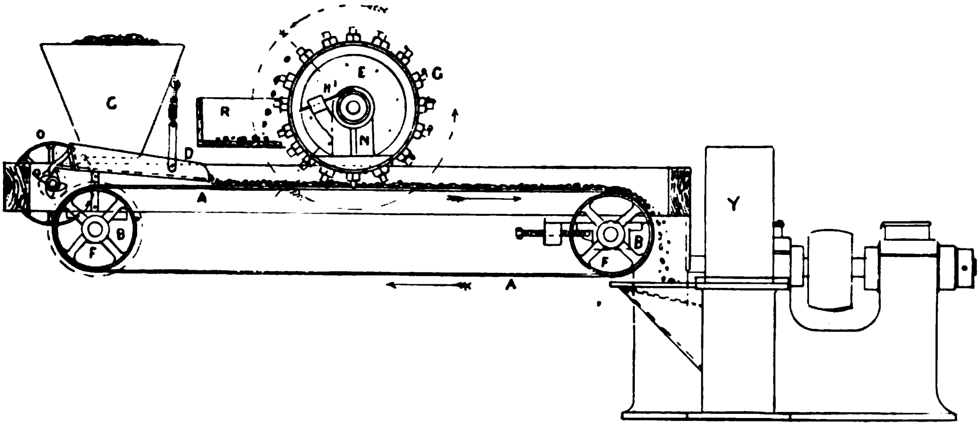


FIG. 97.—Magnetic Separator

There are two types, one in which electro-magnets seize upon the magnetic particles, carry them round, and, being demagnetised, drop them into a box. One of this type is shown in Fig. 97, by C. E. Hall, Sheffield.

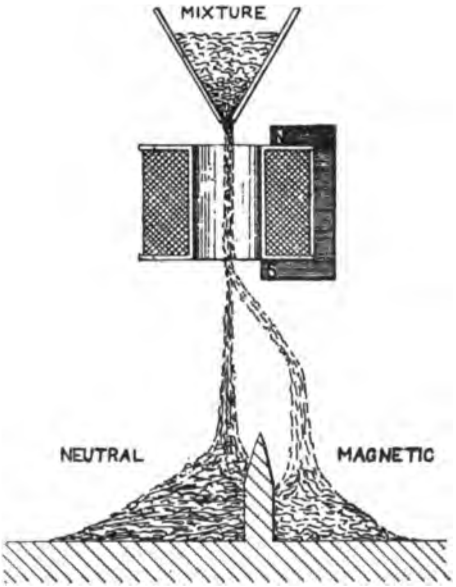


FIG. 98.—Magnetic Separator

The magnets are radial bar-magnets, projecting poles of which may be seen on the drum E; they are magnetised by a current for about two-thirds of a revolution.

The operation is as follows: Unground material in which iron particles exist is fed from the hopper C by the shaking shoe D on to the belt A, at a speed of, say, 80 feet per minute. The rotating magnet's circumferential speed is, say, 700 feet (lineal) per minute, so as to search amongst the advancing material and push it over and forward. Any metallic particles are seized and conveyed to the box R, into which they drop and pass down a side shoot.

The machine can be made to deal with any quantity of material in which iron is present, such as cork, bark, wood, leather, bone, ashes, and refuse clinker from destructor furnaces, metal ores, &c.

It would in some cases be as well to combine a small dynamo on these machines, so that they could be set to work anywhere merely by driving them; it is not everywhere an electric current can be got to work them.

The other system is the Edison, in which there is no moving machinery; and for small machines even permanent magnets may be used. It is shown in principle in Fig. 98. The materials are fed through a hopper, and fall past a magnet, which deflects the magnetic portions into one box, while the non-magnetic falls into another. These have been used on a very large scale in separating iron ores.

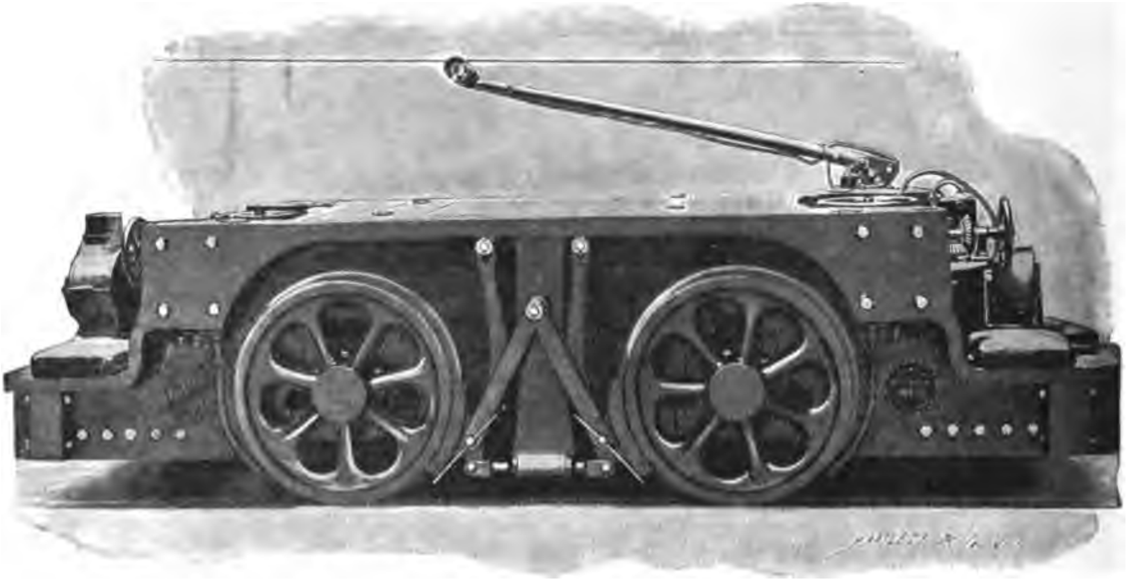


FIG. 99.—Electric Mine Locomotive

Electric haulage in mines is carried out both by locomotives, Figs. 99 and 100, and by fixed electric hoists or drums driven by motors, Figs. 101 and 102.

Locomotives, of course, can only be used in large main roads, and few mines in this country can use them, a preference being given to endless ropes or main and tail rope haulage. The locomotive is much used, however, in mines abroad, and may be of much value in colonial mining, where water-power for generating current may be available.

The Westinghouse Company in conjunction with the Baldwin Locomotive Works have introduced many locomotives into mines suitable for this class of haulage.

The Norton Coal Company, of Norton, Va., is a case in point. The seam of coal is nearly level and of fairly uniform thickness. There are two mines now in operation under the town, with an output of about 550 tons per day. The electric power station is near the entrance to one of the mines, and contains a Westinghouse 100-kilowatt 250-volt multipolar generator belted to a steam-engine. The trolley wire extends 4000 feet into mine No. 1 to the face of the workings, and from the drift mouth 800 feet to the tipple. A feeder line extends 2000 feet into the mines. These wires are carried overhead, the trolley line being divided into four sections, each of which can be connected at will, and independently of the others.

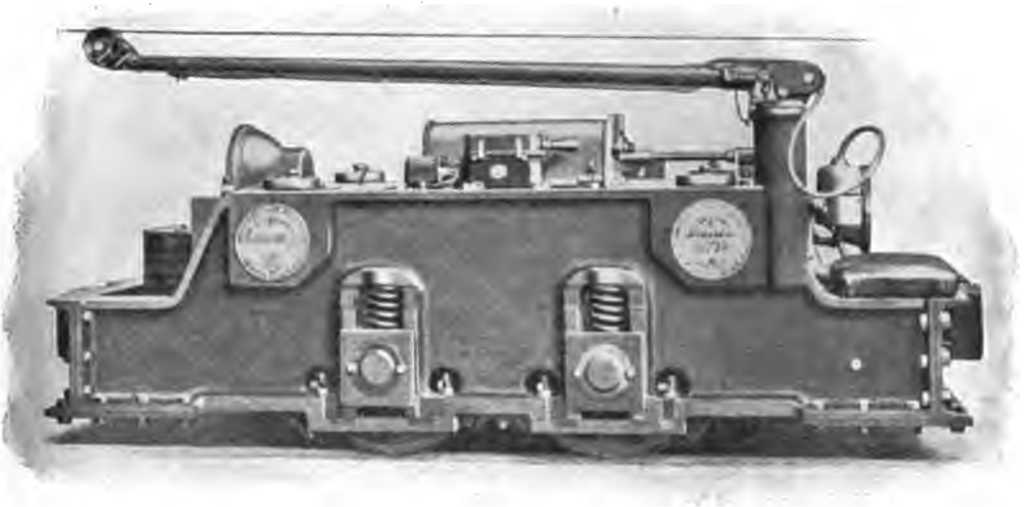


FIG. 100.—Single End Locomotive

Thirty-pound rails are laid in a single-track line of three feet gauge. The electric locomotive, weighing 10 tons, hauls 18 cars with a total load of 36 tons of coal up a maximum 3 per cent. grade. Formerly, a steam locomotive hauled the cars out from a point 1700 feet within the mine, mules being used to collect the loaded cars and to bring them over a distance of 2300 feet to the locomotive. Each train of cars had to be broken up into two or three sections and hauled separately over certain portions of the up grade on a sharp curve. The electric locomotive was introduced in this mine for the sake of economy in operation, as well as to increase the output. It now takes the entire train of 18 loaded cars all the way up from the face of the workings to the tipple without any break.

Electric haulage has enabled the company to double the output of the mine, and the cost of traction has been reduced from about eight cents per ton to one cent per ton, though to this, of course, must be added interest upon the electric investment. This is one of the instances in which the saving brought about by electric haulage amounts to 30 per cent. upon the sum invested in the power plant.

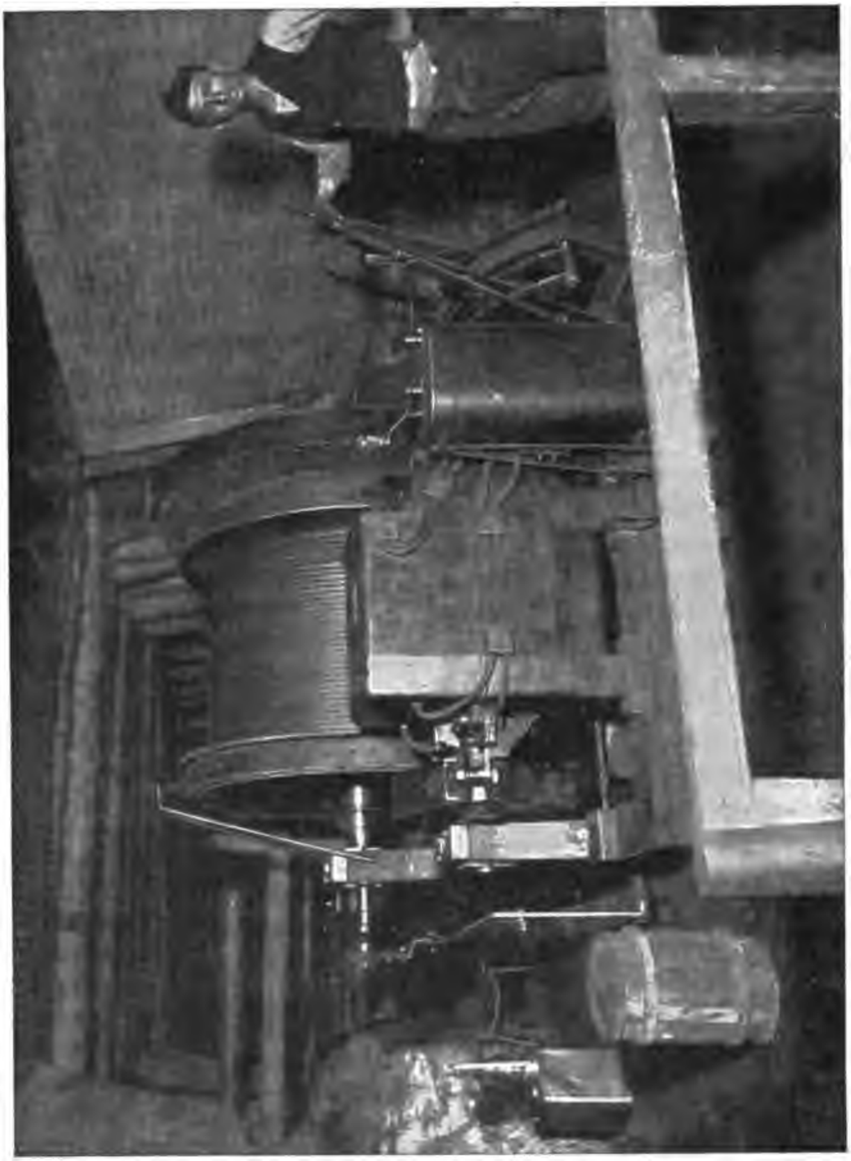


FIG. 101.—Single Drum Mine Hoist

The Company also uses electric current for operating coal-cutters and other mine machinery.

The locomotive is driven by two motors, separately spring supported, one geared to each axle by single reduction gearing, the gears being enclosed in oil tight casings. These motors are designed especially for mine service, and are of the four-pole, steel-clad, enclosed railway type. The armature is of the iron-clad type, the coils being held in slots below the surface and secured from displacement, as in the most approved railway practice.

The locomotives are designed to run at a standard speed of six miles per hour when developing their full load tractive effort. With a light train, requiring less than full load upon the motors, the speed of the locomotive will be increased. When starting, the train is brought gradually up to full speed by means of the controller.

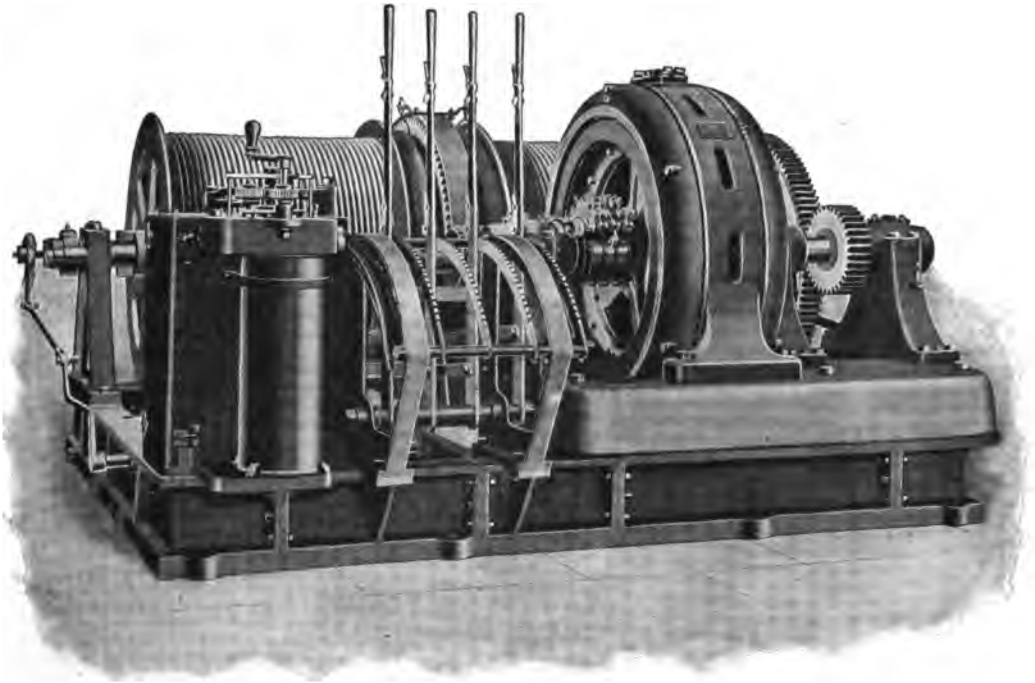


Fig. 102.—Double Drum Mine Hoist

Coal-mine waggons having loose wheels on fixed axles seldom show less than 20 lbs. friction per net ton weight, and for average mining conditions 30 lbs. per ton is a low figure. With the holes in the wheels worn out of true, or with wheels scraping against the sides of the cars, the friction may amount to 60 to 70 lbs. or more. If the track is out of surface or gauge, and if the cars are overloaded, an indefinite amount of train resistance will be added. It will readily be seen, therefore, that any figure estimating the number of tons of trains hauled by any given size of locomotive may be entirely misleading, unless based upon a thorough knowledge of the individual mine in question.

The locomotives are made single and double-ended; the double-ended ones have controllers and switches and seat for drivers at both ends.

Plate V. shows a single-ended locomotive with driver in place, and a double drum winding hoist for pit head working.

The haulage by fixed motors and drums is more often used in our coal seams, usually by endless rope. Fig. 101 represents one fitted with the British Thomson-Houston motors and controllers with a single drum, and a double drum machine is shown in Fig. 102 with an induction motor and controller.

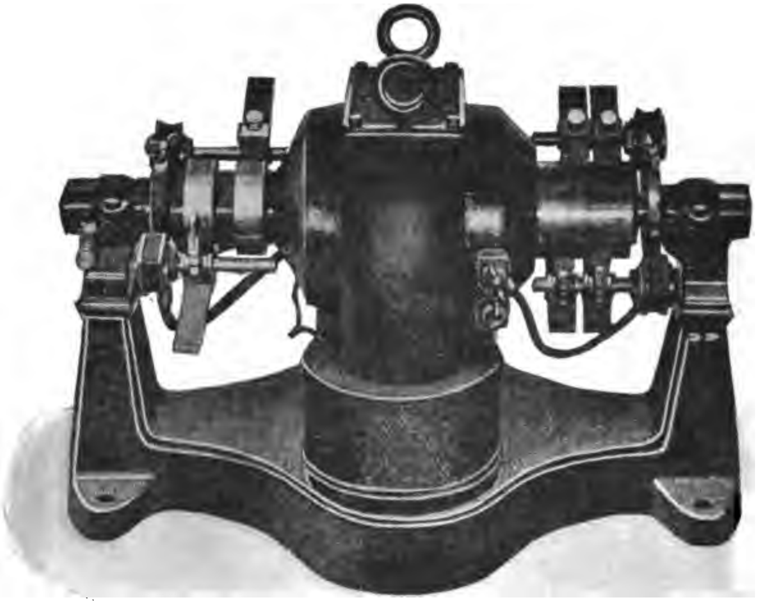


FIG. 103.—Electric Generator for two Currents Alternating and Continuous

There is the question as to what current to adopt in mines, continuous or alternating. It is one for careful consideration in each case; but, generally speaking, in laying out a scheme for large mining operations wherein the applications of electricity are so diverse in nature, and the power being the most important side of the problem, and long distances have to be considered, the three-phase system has on the whole much to commend it. But perhaps a double-current system would be better; in fact would be necessary if locomotives are to be used about the mine, for they require continuous current. It will be found that in any large, comprehensive scheme for electric lighting and power transmission in mining the two currents will find their special adaptations required.

For haulage, pumping, coal-cutting below, three-phase induction motors have some advantages, while for variable speed motors or Loco motors, the continuous current has the advantage.

If steam is the working fluid, the steam turbine plant is to be preferred above all others for generating the currents. Two plants are required at least, so that one can be always relied upon for use in case of stoppage of the other.

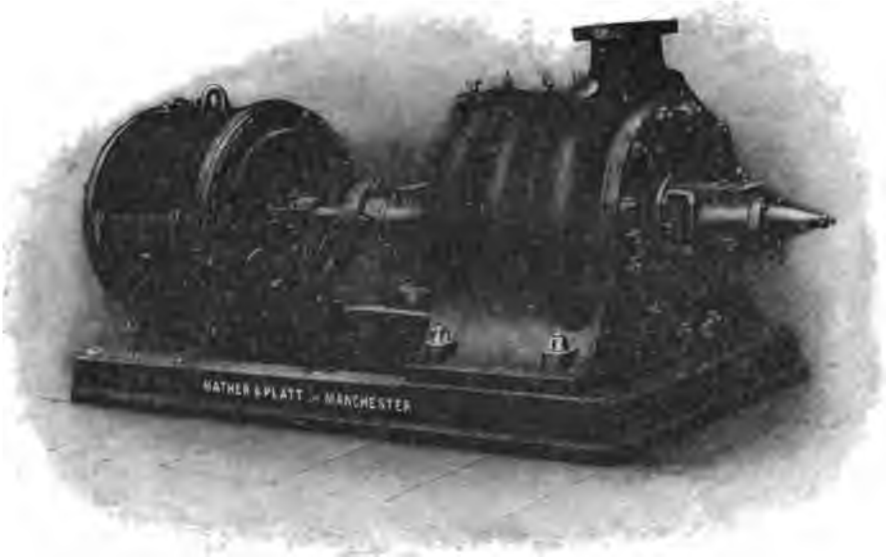


FIG. 104.—Centrifugal Pump

The three-phase currents can be obtained from three slip rings on the shaft of a continuous current generator, as explained, page 114, Vol. I. of this book. Fig. 103 is an example of this double current generator, with two slip rings shown on one end and an ordinary collector on the other end. For three-phase currents three rings would be used instead of two. It is therefore not necessary to have two sets of different machines. The high speed of the turbine also favours this double-current machine, from which at one end we can draw continuous current at say 500 volts, and three-phase current at a somewhat smaller voltage—about 350. This then, by a ten-to-one transformer, could be raised in pressure for transmission below, for use through step-down transformers at the machines to be driven.

This system, of course, is only for large schemes. It would be too complicated for ordinary coal-mines or iron-mines. But in adopting turbine steam generators, it is wise to have the three-slip rings connected up and fitted with brushes, so that at any future time the three-phase alternating currents can be used when desired.

Mining pumps driven by electricity are very common of both types, the three-throw ram pump and the centrifugal pump. The centrifugal pump is very well adapted for direct coupling to the motor, as it is a high-speed machine naturally.

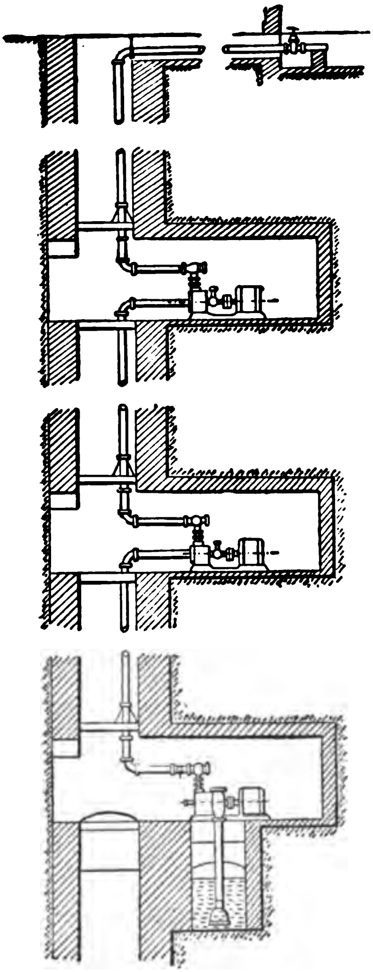


Fig. 105.—Electric Mining Pumps in Series

Messrs. Mather & Platt's high-lift multiple centrifugal pump is shown in Fig. 104.

The multiple centrifugal pump was invented by Professor Osborne Reynolds, and introduced by Messrs. Mather & Platt, and is known as the Mather Reynolds.

The peculiar feature of the pump is that it may consist of one chamber or a series of chambers, each chamber being furnished with a complete set of vanes. The fluid is discharged from the channel surrounding the first set of vanes with a certain pressure. In the second set this pressure is doubled, in the third it is trebled, and so on, until the discharge orifice is reached.

Thus, in the case of a pump with four chambers and four sets of vanes, if the water leaves the first chamber with a pressure of 30 lbs. per square inch, it will, on leaving the fourth, have attained a pressure of $30 \times 4 = 120$ lbs. per square inch.

Further improvements, which enable it to work to much higher lifts with a single chamber, and to obtain higher efficiencies, have been made.

In this improved type of centrifugal pump the water enters the revolving wheel axially, and in the case of single chamber pumps symmetrically on each side, so that the axial thrust is eliminated; the water then traverses the curved passages of the wheel, and is discharged tangentially at the periphery into guide passages which convey it to a whirlpool chamber, where the velocity head imparted to the water by the wheel is converted into pressure head. From this chamber the water is finally discharged into the pipe lines, or in the case of multiple pumps into the second and following chambers.

A special feature of this type of centrifugal pump is the provision of a channel in the body of the pump, concentric with the vanes, which enables the conversion of velocity head into pressure head to be carried out more perfectly, and therefore not only greatly increases the possible height of lift, but also materially improves the efficiency of the pump.

An interesting case is given of an instance of very high lift by means of these pumps in series in a Spanish silver-mine delivering 1000 gallons per minute against a total head of nearly 1500, and run with 15 per cent. less coal than was used in the best ram-pumps previously used.

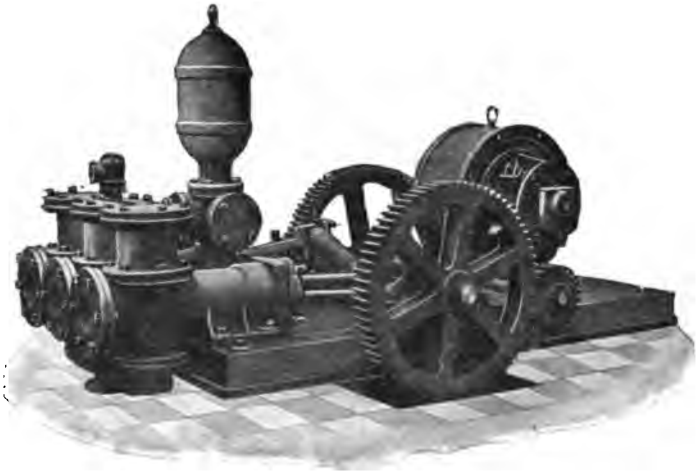


FIG. 106.—Three-Throw Pump driven by an Electric Motor through Reduction Gearing

Each chamber in the shaft shown in Fig. 105 is only

26', 11" × 6' × 11', 6".

We give, in Fig. 105, a diagram of the arrangement of this plant. It will be seen that there are three sets of pumps, each capable of forcing 1000 gallons per minute against a head of nearly 500 feet.

The lowest pump draws directly out of the sump and discharges straight into the suction of the pump pipe 500 feet above, no lodgment for water being necessary; the middle pump in like manner, drawing direct from the first, delivers straight into the third or top pump, so that the column of water is entirely unbroken, and constantly flowing steadily onward.

Plate IV. represents an electrical pumping station fitted by these high lift pumps. Their great simplicity, efficiency, and absence of stuffing glands, valves, and rods, are great recommendations in mining installations.

Fig. 106 represents the same firm's three-throw ram-pump operated by electro-motor and geared down by wheel gearing. Worm-gearing is often used and works silent, and is more compact. Silence in coal-mines, especially near the face, is sometimes of importance, for falls of roofs or curving in of sides are often preceded by warning cracks and sounds, giving notice of impending trouble.

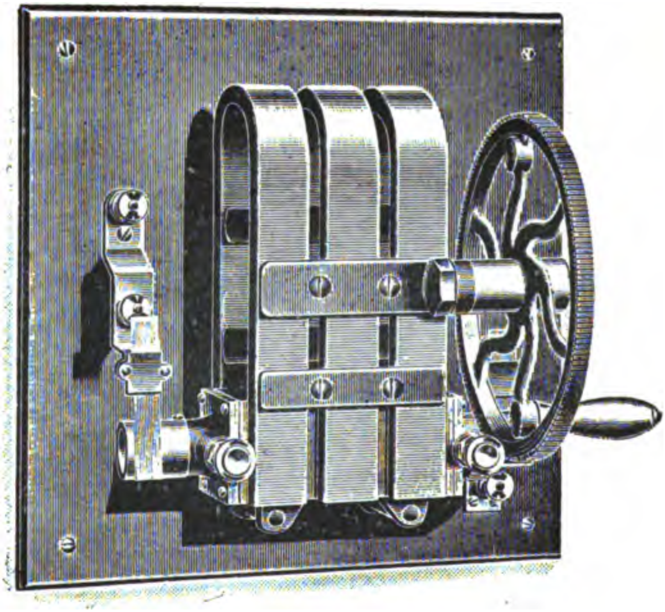


Fig. 107.—Magneto Exploder

Firing shots in mining operations is in many cases resorted to. It is by far the safer method of firing these shots to employ electricity; there is then no uncertainty as to the miners reaching a place of safety before firing the shot. It has also greater advantages in volley firing, wherein it is important that a number of shots should be fired simultaneously to obtain these combined effects.

The generator most generally serviceable is the magneto-electric machine or small dynamo; great pressure is undesirable, 10 to 25 volts being sufficient for one-man jobs. A small magneto machine, such as shown in Fig. 107, will explode 30 to 50 shots simultaneously.

A modern design for an exploder should have a fixed armature, no rubbing contacts; a rotating permanent field-magnet should be used fixed to a strong steel shaft, and geared to a strong hand-crank, as shown in diagrams Figs. 108 and 109.

The fuse is a matter of importance: it should consist of wire not readily corrodible, and the following are Professor Abel's instructions on this point:—

Uniformity in the resistance of wire fuses made with one particular kind and size of wire depends obviously, in the first instance, upon the employment of the same length of wire as the bridge in each fuse. With a view to attain this end the copper terminals must be accurately fixed at the same distance apart in the several fuses; the wire must be always uniformly stretched across between these terminals (and therefore strained from one to the other as tightly as possible), and its two extremities must be attached to the terminals as uniformly as possible. The following general directions for constructing the terminals and wire bridge will indicate the manner in which uniformity in the resistance of the fuses may be attained:—

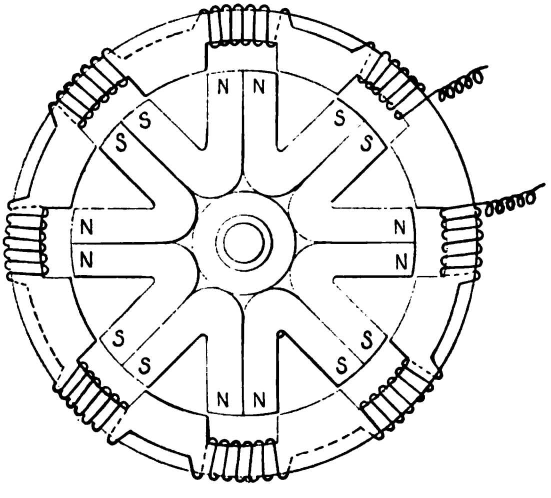


FIG. 108.—Magneto Exploder

The bared ends of the insulated copper wire which are to form the terminals are firmly fixed at a uniform distance apart (0.25 inch is found a very convenient distance) by being inserted into a die or mould, and partly embedded, while in that position, in a plug of some very hard cement or composition, which attaches itself thoroughly to the copper surfaces. A mixture of plaster of Paris or Portland cement and sulphur, which is cast round the wires while sufficiently hot to be viscid, is a good material for the purpose; or the wires may be embedded in a plug of india-rubber preparation of the proper composition for subsequent conversion into ebonite. In either case the sulphur, which is a component of both preparations, attacks the surfaces of the copper wires, and thus ensures their being quite immovable when the plug has cooled. The bare ends, or terminals, should project about 0.25 inch beyond the plug in which the wires have been fixed, and should be uniform in length and well brightened. In stretching the fine wire across from one terminal to the other, pains should be taken to do this always as tightly as possible, and in a perfectly horizontal line, so as to ensure the employment of uniform lengths of wire in different fuses. Means should be adopted for making the terminals hold the wire, by the obvious expedient of roughening the surfaces of the copper, or of cutting a fine slit into their extremities, into which the wire may be inserted. The latter should, when properly strained and wrapped round, or let into the terminals, be firmly attached to these with solder, carefully applied by means of a small rod to *the back* of the terminals, so as not to be brought into contact with the wire bridge itself.

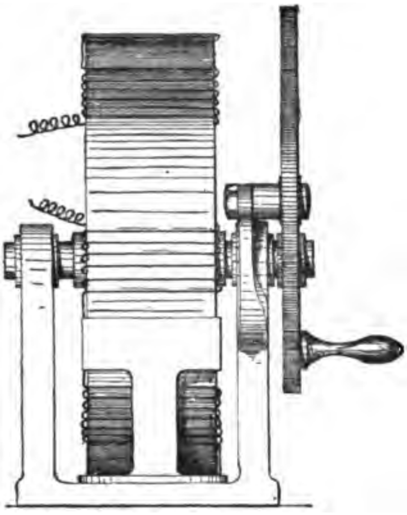


FIG. 109.—Exploder

Either gun-cotton or gunpowder is now very generally employed as a *priming* agent in platinum-wire fuses—*i.e.* as a means of facilitating the production of explosion by such fuses. The best wire is platinum or platinum silver for fuses to be made up and kept a long time before use, but if made up for immediate use cheaper German silver wires may be employed, and these cheap fuses may be made to keep well for some time by slightly coating with cold lacquer after being soldered up and before fixing into the priming.

CHAPTER V

ELECTRIC TRACTION

THIS class of installation is remarkable only from the immense scale on which it has been introduced. The electrical engineering of electric traction systems is of the simplest and most primitive order; no problems of any complicated or of an order requiring highly educated electricians ever presented itself in electric traction.

When electric traction was introduced at first, everything electrically necessary for its success had been worked out fully, years before, by pioneers who do not even receive recognition now.

The first thing to be done was to gear an electro-motor to a tramcar axle; the electro-motor was at hand all ready, so was the gear.

The next thing to be done was to set up a generating station for producing the electrical energy; the existing stations for power and light had only to be copied for the purpose. The third thing necessary was to provide a sliding electric contact along the railway route to supply the energy to the moving car. There were two very old methods to choose from for this purpose. First, a third rail insulated all the way, with a rubbing collector trailing from the moving car. Second, an insulated overhead wire, with a trolley drawn along by the car, making contact. Then a switch for stopping or starting and regulating the speed was required. How that should be constructed was well known to electricians years before any electric traction was established.

The whole of the elements of successful electric traction were perfectly well known and far beyond any experimental stage when the present engineers adopted them, and established the present systems; they had only to design the mechanical details to bring the whole up to the practical requirements of everyday service on the road. These secondary problems required ordinary mechanical engineering experience for solution. The electric generator had to be capable of withstanding very heavy fluctuations in the current. The motors had to be enclosed and also capable of withstanding the rough work, and their gearing required special adaptation to keep it properly in gear and allow of some elasticity between the motor support and car truck.

The switches and resistances for controlling the car had to be put up in a compact form easily worked by one handle, so that un-

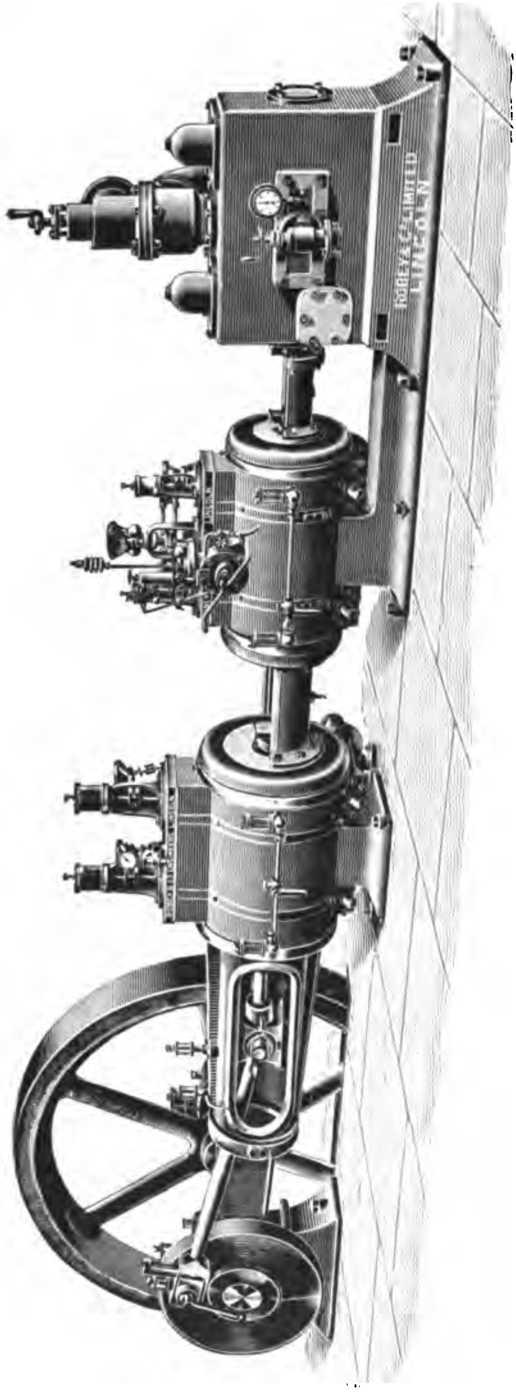
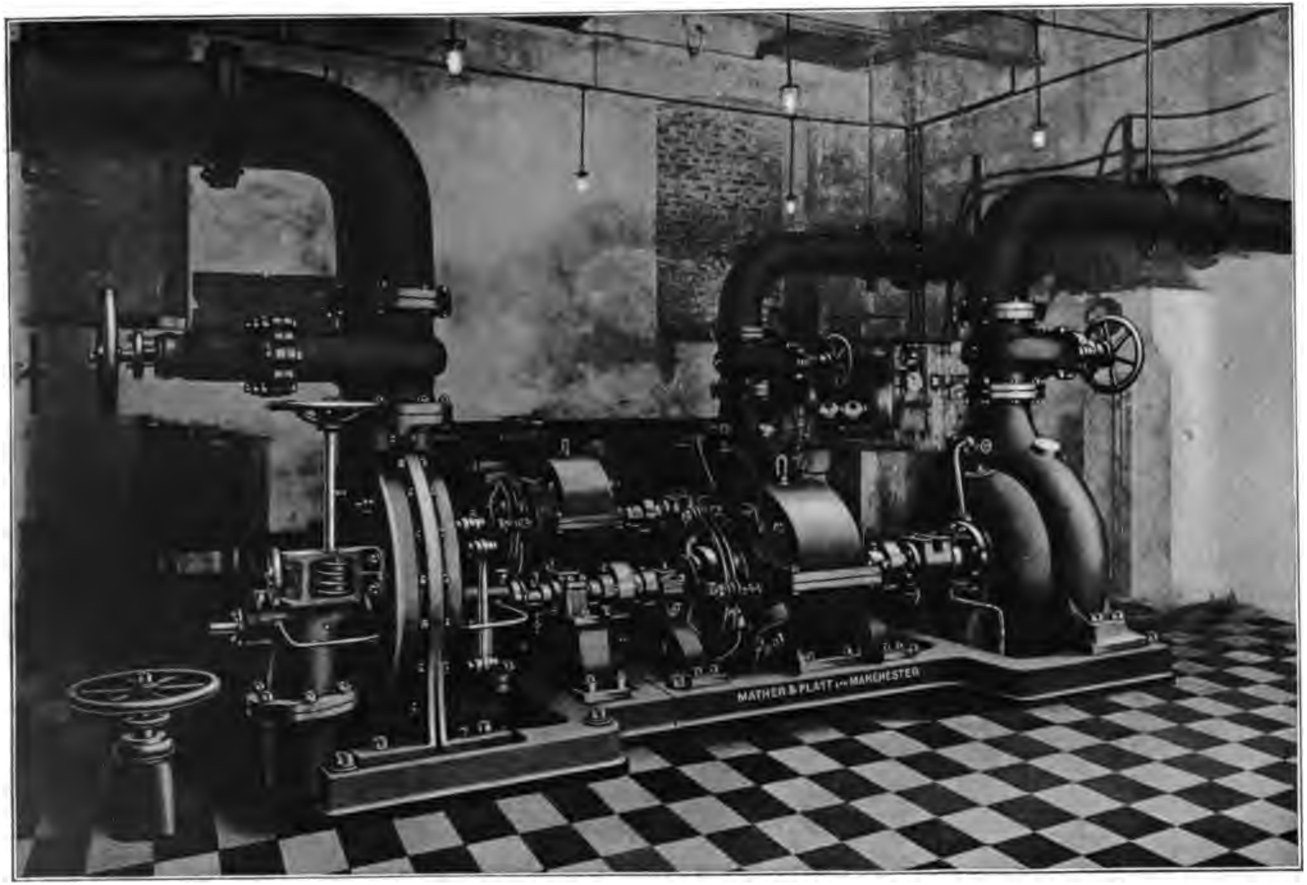


FIG. 110.—Robey Tandem Compound Engine

skilled men could drive the car. The trolley wire required properly designed supports and insulators to carry a heavy wire safely overhead. All these were simple problems, and as a consequence when some one induced capital into a proposal to work electric. traction commercially, there were no engineering obstacles whatever to going ahead successfully from the first.

In America capital is always ready for this purpose, and there the first electric street railways were introduced years and years before anything in this way was done here. The same American capitalists introduced it on this side, and secured all the lucrative contracts for the equipment of the larger towns and cities in Great Britain, wherein it has in every case proved an immense commercial success. Such is a brief review of the electric traction history from an electrician's point of view.

The electrical appliances have of course been developed in the direction of the special requirements for electric



TWO HIGH-LIFT CENTRIFUGAL PUMPS, EACH 1250 GALLONS PER MINUTE, AND 95 FEET HEAD, FOR CIRCULATING WATER THROUGH CONDENSERS

Each Pump is driven by an electric motor assisted by a turbine actuated by the return flow from the condensers

traction, and each element is worthy of notice so far as it is electrically concerned.

The generating station for electrical transmission of power to vehicles on roads and railways has nothing special about it. American engineers attempted to establish a superstition that electrical generators for traction purposes required a particularly designed engine for driving the dynamos, something with an enormous shaft diameter and an enormously heavy fly-wheel; this notion was carried out to an absurd extreme.

The people who purchase and pay for electric traction machinery in towns and cities, knowing no better, accepted this notion at first; better knowledge of the subject now exists, and we find that well-made British engines are quite superior for the purpose. And there is not the slightest doubt about the fact that for electric traction generators, the Turbo Electric Generator is by far superior to any other form of steam plant.

A gas plant is possibly more economical, and no doubt will be the future power for traction purposes in many larger schemes.

Where slow-speed engines are preferred, there is a good deal to be said in favour of the tandem compound single-crank horizontal engine, such as shown in Fig. 45, Vol. III. But this type of engine should have double heat or Cornish valves similar to the Robey engine shown in Fig. 110, or to the Proell gear, Figs. 62 and 75, Vol. III., as these valves can be run at higher speeds than the Corliss valve, and superheating can be carried further with these valves than with the Corliss type.

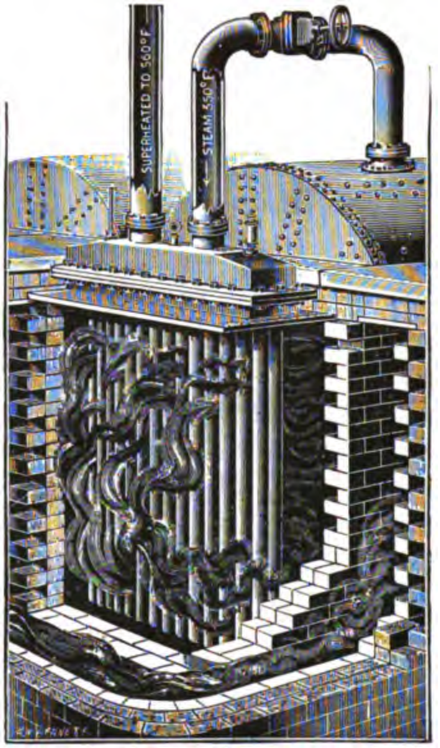


Fig. 111.—Superheater, Anderton's

This class of engine, however, can only be preferred on account of some special circumstance; it takes up a great deal of space, requires immense fly-wheel energy, the moving parts are massive, requiring equally massive foundations. It can be said for it that highly superheated steam may be used to obtain economy, while superheating in steam turbines has not so much effect on economy.

In the impulse turbine it is not of any advantage, for superheating lessens the weight of steam per cubic foot, while the impulse is proportional to $\frac{mv^2}{2g}$, in which m is weight.

In the Parsons' turbine it is also of little advantage, for it also works principally by impulse, so that only moderate superheating is advisable for any known steam turbine, merely sufficient to ensure dry steam during its passage through the turbine.

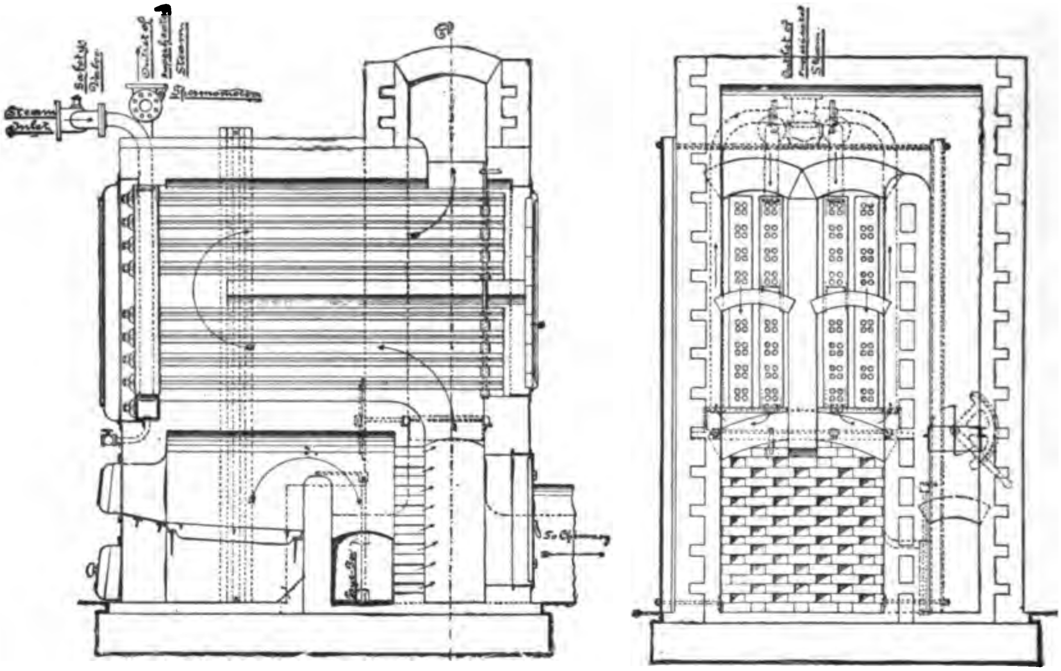


FIG. 112.—Separately Heated Superheater

It is only in a purely pressure turbine, such as those based upon the principles of Barker's Mill, that superheating is of any great advantage. In any steam turbine which acts by the weight of steam at high velocity thrown upon vanes, superheating beyond sufficient to dry the steam is useless or worse.

On the other hand, in the big, lumbering, slow-speed engine, with its immense cylinder cooling area, superheating to a high degree is beneficial; the weight of the steam is of no account whatever in calculating the pressure on the piston in these engines. We may mention two superheaters, one for placing right in the path of the hot gases coming from the flues of a Lancashire boiler, shown in Fig. 111. It is a simple tubular apparatus, and can be fitted to any boiler. This superheater is far better than steam driers, for even a moderate amount of superheat ensures dry steam.

The superheater for separate firing requires an additional 10 per cent. of fuel for the superheat, but the gain in using superheat to a high degree in these slow-going reciprocating engines is as much as 20 per cent. Fig. 112 shows the Babcox and Willcox separate fired superheater.

To take an extreme case working at 160 lbs. pressure saturated steam, a large tandem compound engine would take about 14 lbs. per I.H.P., whereas by heating to about 600° F. the consumption of steam would drop to about 10 lbs. per I.H.P. The makers of the Schmidt engines have accomplished this.

But no such gains can be realised with velocity turbines.

Hitherto the continuous current has been universally adopted for traction work in order to obtain complete control of the motors. Alternating motors have only one speed, and that a maximum as ordinarily constructed; but by recent improvements some motor designs and improved methods of working and controlling have made it possible to operate traction motors by alternating currents.

Whatever current is employed the generating station is not a very important engineering subject. There are no problems to solve in the matter of establishing a generating plant; it can be summed up in the common tender form—

Boilers, including feed-pumps, economisers, superheaters, and accessories.
Engines and dynamos.
Condensers and cooling water.
Switchboard and instruments.

It is principally an ordinary mechanical engineering job, in which the engineer must select the best plant for the purpose, and for the special case in hand.

Wherever enough water is available for steam and condensing, the engine should be a steam turbine. Where water is scarce, the gas or oil engine comes in. In colonial work in Australia and South Africa, where water is often not to be had for long periods, gas and oil engines are available, and produce the electrical energy cheaper than a reciprocating steam engine or turbine without a condenser.

In previous volumes we have already reviewed the engines and dynamos fully, it remains now to consider the special electric traction apparatus.

The application of accumulators as boosters on a traction system is fully considered in Chapter I. Vol. III. The first necessity in a traction system requiring the attention of the engineer is the conductor, whereby the power of the generator is to be carried and supplied to the moving cars.

Traction Transmission Systems

There are three systems:—

(1) The surface contact system.
(2) The underground conduit system.
(3) The overhead trolley system.

Dr. John Hopkinson first proposed the surface contact system in 1882. Briefly, his plan was to employ an electro-magnetic switch, shown in diagram, Fig. 113, to put the rails or studs in connection with the supply conductor. This switch was to be operated by a current passed through its coils from the car as it came into contact with the rail or stud with which the switch was connected.

The two double lines in the diagram are the rails, one shown in insulated sections, the lower line is the insulated feeder cable.

It was difficult to insulate such a system, and this insulation difficulty has been the trouble with the surface contact systems hitherto tried.

The Johnson-Lundell surface contact system is one of the latest and perhaps best one now before the public, and as it very well illustrates this system, it will be described fully.

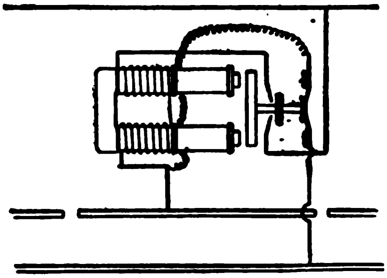


Fig. 113.—Magnetic Switch

The surface contact system delivers the electric current to the car motor by effecting contact with a supply conductor placed in the surface of the street instead of one placed on poles overhead, as in the case of the trolley, or placed in a conduit underneath, as in the case of the open slot conduit system. It will be apparent from this comparison that whereas the overhead system is objectionable from the aerial obstruction offered by the poles and wires, and the conduit system from the obstructive and insanitary nature of the open slot, as well as because of its great cost, the surface system is in no way open to any such objections. It is, in fact, less obstructive and cheaper than the open slot system, and is hardly more expensive to install than is a properly constructed overhead system.

From the fact that the supply conductor is placed in the surface of the street, and therefore subject to contact with animal traffic, it follows that such supply conductor must not be electrically charged except when in actual contact with, and therefore when covered by, the moving car. It will be apparent from this that the surface supply conductor must not be continuous, but must be sectionally divided so as to limit the charged sections to those immediately underneath the moving car. The electric current must in fact be made to advance from section to section in synchronism with the advancing car. These sectional conductors—originally rails of several feet in length—have finally come to be nothing more than "studs" of from six to eight inches superficial area, and placed in the centre of the roadway about ten feet apart. Each of these studs is electrified by means of an automatic switch which is controlled by the moving car, thereby placing the studs consecutively in electrical connection with the buried main supply conductor as the car reaches them, and in like sequence disconnecting them from such conductor as the car leaves them. The car motors are thus enabled to draw a continuous supply of electric energy from the buried main through the studs, whilst animal traffic following in the wake of the cars is protected, providing the automatic switches do not fail; to use a vivid descriptive term employed by electricians, the studs are intended to be "alive" underneath the car for the purpose of its supply, but to be "dead" to all other traffic; here is the crux of the whole problem.

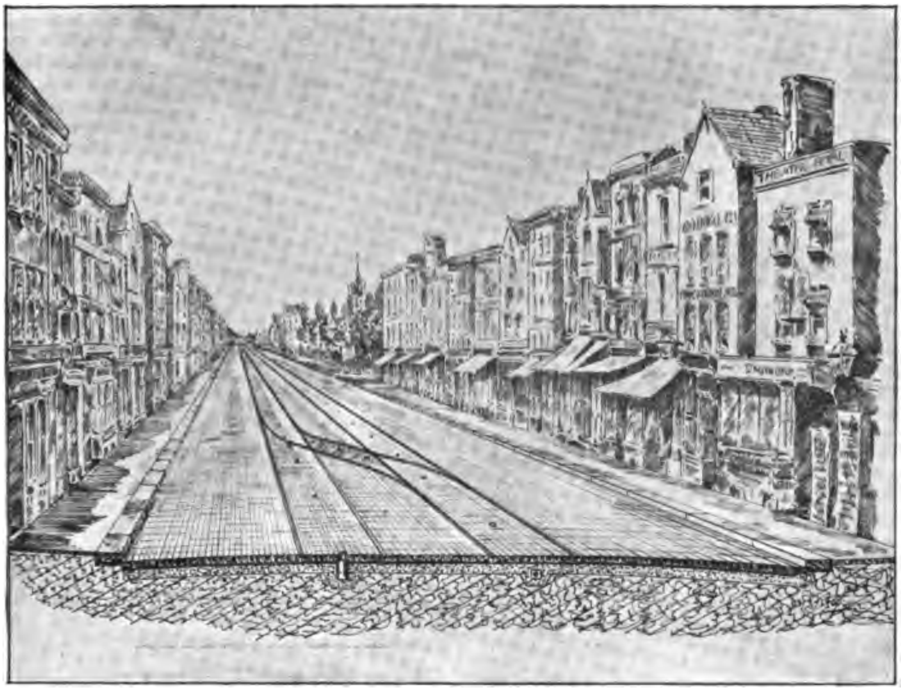


FIG. 114.—Surface Contact System

If we bear in mind that a "live" stud, even though undisturbed and in its proper place, is as innocent looking as a "dead" one, we will at once recognise the fact that the sole responsibility for an accident to man or beast arising therefrom must fall upon the tramway.

Surface Contact Systems

The surface contact system is illustrated in Fig. 114, showing the street intact and no overhead obstructions.

Nearly all proposals have had the same objections as Hopkinson's, that is, the liability to failure, and leaving a stud alive.

As we shall presently see, this fatal defect of the original electromagnetic switch system was more or less present in all subsequent methods of its application until the Johnson-Lundell scheme of 1894.

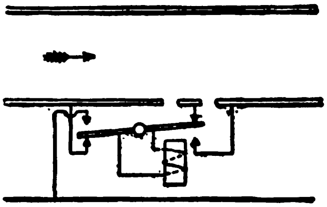


Fig. 115.—Magnetic Switch

Ayrton and Perry's system is shown in diagram, Fig. 115, and Pollock and Bingswanger of 1886 is shown in Fig. 116. These later inventors were the first to exhibit a full appreciation of the vital importance of safe-guarding the street from leakage. They developed the idea of operating "armature" switches in the streets by means of magnetism developed upon the car, and transmitted through the street pavement to the buried switch.

The underlying idea involved in this method is inherently sound, since the magnetic force employed to operate the switches must of necessity all pass away with the moving car, and not, as in the case of electric force, leave a remnant in its wake possibly of sufficient strength to keep the switch closed.

Nevertheless, the principle has not been found adequate, because of the indecisive and unreliable work capacity of magnetism when dealing with heavy currents and high speeds, and operating through a more or less uncertain magnetic circuit.

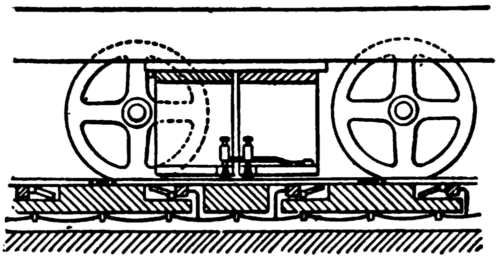


Fig. 116.—Contact Maker

Mechanically operated studs, which work like pistons, rising to make contact under the car, bringing into operation a series of pistons subjected to frequent sharp blows, even when under the favourable conditions of factory enclosure, it needs no argument to demonstrate the utter impracticability of attempting to maintain such arrangements in effective working order upon the surface of a street, or even when placed in a shallow conduit, as has sometimes been proposed. Nor does it matter whether such piston action is reciprocating or rotary, the inevitable result is the same; moreover, exposed to the weather in a severe climate, its failure would, in any event, be guaranteed in the presence of snow and ice.

We therefore have three types of switches : the electro-magnetic, the simple magnetic, and the mechanical, each with limitations debarring it from achieving the essential certainty and positiveness in action.

The objection to the electro-magnetic system is the liability that the switch may be held on by a leakage current after the car has passed.

The most effective arrangement for neutralising the effect of leakage currents upon the controlling switches was that introduced in 1894 by Messrs. Johnson and Lundell, and termed by them the "Leak Circuit." Fig. 117 represents this scheme, interposing two studs between the supply conductor and the switch magnet. One of these was placed in the centre of the roadway, and the other outside of the track rails. The negative, or return conductor, *i.e.* the track rails, was thus interposed between the two studs, making it necessary to form a bridge over the rails in order to effect electrical connection between them. This was, of course, readily done for the power current required by the motor, but with the passing of

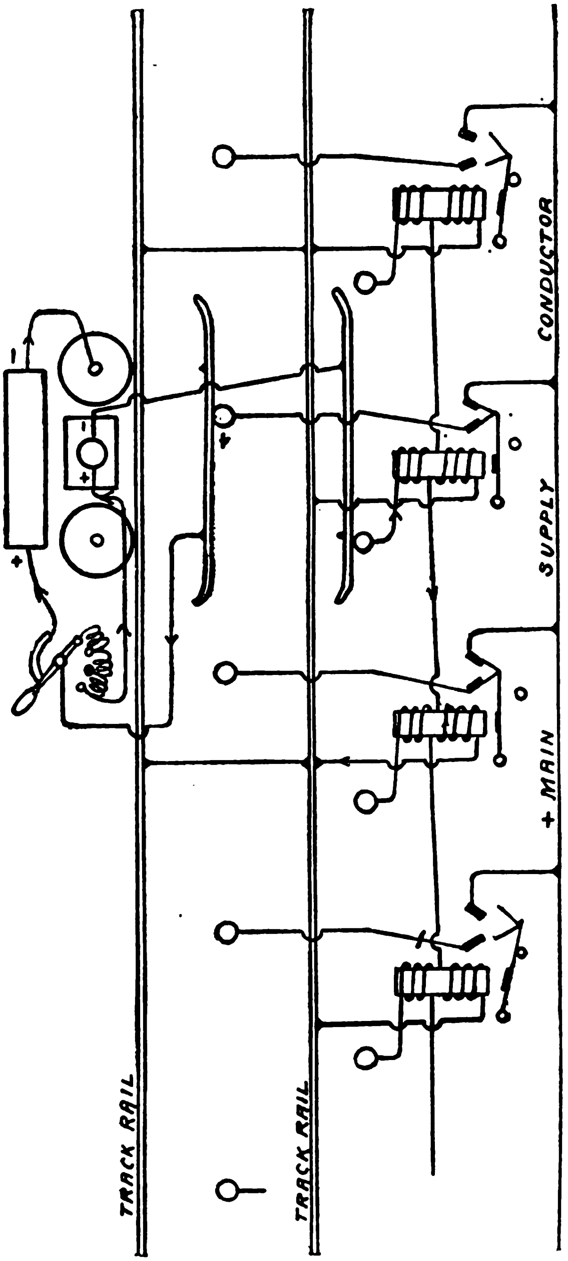


Fig. 117.—Surface Contact System

the car the bridge also passed, and thus effectually closed the path

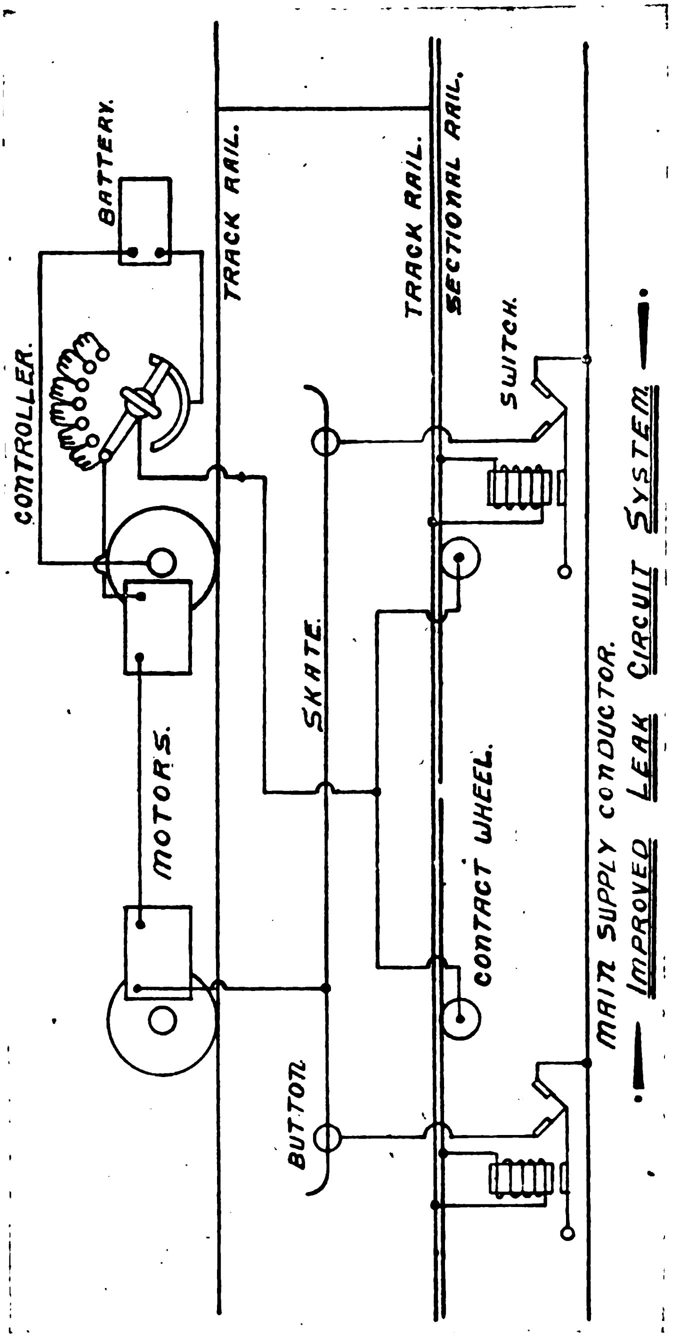


Fig. 118.

for leakage from the supply stud in the centre of the roadway to the switch stud outside the track rails; the latter, being the direct return path of the power circuit, necessarily, became the path of least resistance and all leakage flowed to it, thus leaving the switch absolutely unaffected. This scheme, however, required a number of storage cells on the car, and this was fatal to its success. A new plan was then made, shown in Fig. 118.

As will be seen by an examination of the diagram, Fig. 118, the Leak Circuit principle is retained in the improved system, and the switch is thus, as heretofore, safely energised by a current from the surface of the street. The storage battery is, however, practically eliminated as an objectionable factor by its reduction from the full complement of 250 cells to an inconsequential half-dozen. This is effected by the substitution for one skate and one series of roadway studs, of a pair of bevelled edge contact wheels and a light contact rail, it having been found that such method of effecting contact is entirely efficient for any voltage, however low, and in all kinds of weather.

This contact rail, though of course sectionally divided electrically and isolated from the track rail, is nevertheless in a physical sense practically continuous, and is located in such close proximity to the track rail as to constitute in effect a simple widening of the tread of the latter.

The method of operating the switch by means of a large magnet on the car is shown in Fig. 119. The diagram, though not pretending to disclose the exact detail of the application of the system, will suffice to illustrate its practical operation.

R and R^1 represent the tram rails, which are bonded together in the usual way so as to constitute the return circuit for both the relay and propelling currents, said rails being supported upon cross-ties, T, as shown. B represents one of a series of contact studs secured within protecting cups or casings, B^1, bolted to the cross-ties, T. S^1 represents a contact "skate," or shoe carried by the car, and connected to and through the propelling motor, and to the wheels of the car (not shown), in the usual manner.

F represents the high voltage feeder or main connected to the station generator at the power-house, and W, W^1 are branch feeders running from the current main, F, to the contact studs or sectional service conductors, B. C^1 and C^2 are switching contacts in the branch feeder circuits, and C switching solenoid cores or armatures controlled by coils M^1, located in independent branch feeders W^2 and W^3, of a low potential feeder, F^1, and enclosed in air and water-tight switching-boxes, and connected to an independent dynamo at the power-house, but of much lower voltage than the power-dynamo.

D, D are air and water-tight switch-boxes of non-magnetic material located just beneath the road-bed surface and preferably near the centre thereof. In each of these boxes is enclosed a magnetic relay, here shown as a pivoted magnetisable needle, N^1, located in a plane at right angles to the road-bed, with its free or contact end normally at its lowest position, so that the circuit through the switch coil, M^1, is normally open. It will be apparent that the stationary or magnetic relays enclosed in the switch-boxes, D, are connected in series relation with the coils, M^1, of the switch-controlling electro-magnets.

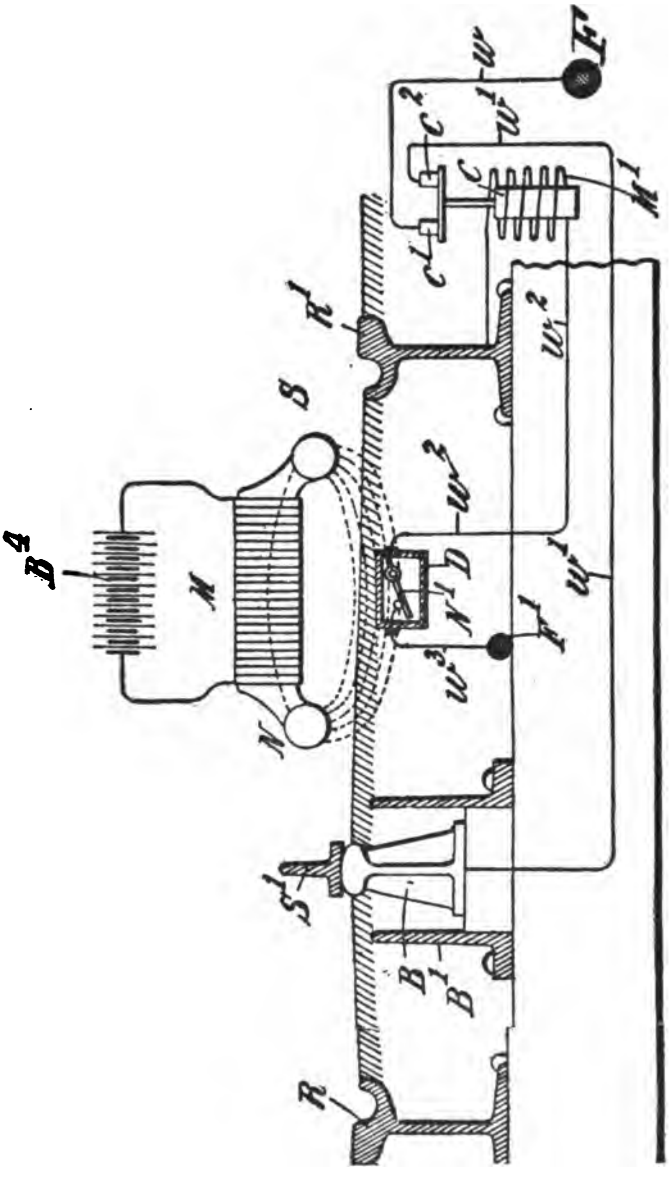


Fig. 119.—Magnetic Switch

Each car or vehicle carries beneath its floor, and in close proximity to the road-bed, a magnetic field composed of two long parallel iron pole pieces, N and S, slightly shorter than the car body. The said pole pieces are connected together at two or more points by magnetic cores wound with energising coils, M, connected in multiple with an electric generator, or preferably a few cells of storage battery, B^4, carried also by the car, the component parts being so proportioned with the relation to the actual relay work to be done, that a powerful magnetic field will be established between the poles N and S, and magnetic lines of force caused to flow at right angles to the direction of motion of the car and in planes parallel with the direction of movement of the relay needles or armatures.

The Lineff system, shown in diagram, Fig. 120, also used an electro-magnet, which pulled up a flexible strip to make contact with the rails. In another proposal a magnet was designed to pull up a stud under the rail.

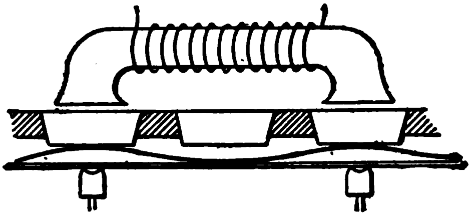


FIG. 120.—Contact Maker

The conduit system is simply a trolley wire under ground, with the trolley pole working through a slot in the road between the rails; the conduit must be well drained to maintain insulation. A perfect system is very expensive; to make it properly requires a cast-iron conduit with plenty of room. The ideal conduit should be wide enough and deep enough to allow a man to walk along, in fact it should be a subway. Fig. 122 shows a street with shallow conduits.

The Blackpool Electric Tramway was the first in this country to try the conduit system; it was designed by Mr. Holroyd Smith. A section is shown in Fig. 121, which will give a good idea of the conduit; the trolley runs between two conductors, carried on insulators.

At present the only case of conduit working is being set up at some parts of London, where the overhead trolley system would not be tolerated.

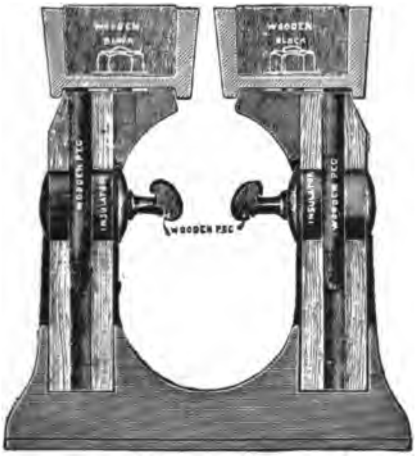


FIG. 121.—Conduit

On the routes of the London County Council's Tramways, between Westminster Bridge and Tooting, Kensington Gate and Blackfriar's Road, St. George's Circus and Waterloo Road, the company's engineers designed a conduit system, to work at 500 volts continuous current. Fig. 123 gives a general view of this conduit, at a bend, showing the slotted central girder and supports; Fig. 125 showing sections. The gauge is 4 feet 8½ inches, and double track.

The slot rails are of steel, Z section, weighing 50 lbs. per yard, with a drip lip along the inner edge of the slot. The width across the heads of the two rails will be 4½ inches. The rails are bolted to the yoke jaws, and further fixed by wooden wedges, the width of the slot being kept as near ¾ inch as possible.

The conductors are two in number, of soft steel tees weighing 23 lbs. per yard, and carried on insulator supports at 15 feet intervals, the supports being arranged midway between the yokes. The insulators are of glazed brown earthenware, with double petticoat (see Fig. 124), mounted on cast-iron stems, which are cemented into the concrete. The curved brackets down to the conductor rails are of gun-metal, and the insulators are fixed by a nut and washer at the top of the stem, leather washers being provided to pinch against. A bell-shaped pot cover is placed over all to deflect any drippings clear of the insulator.

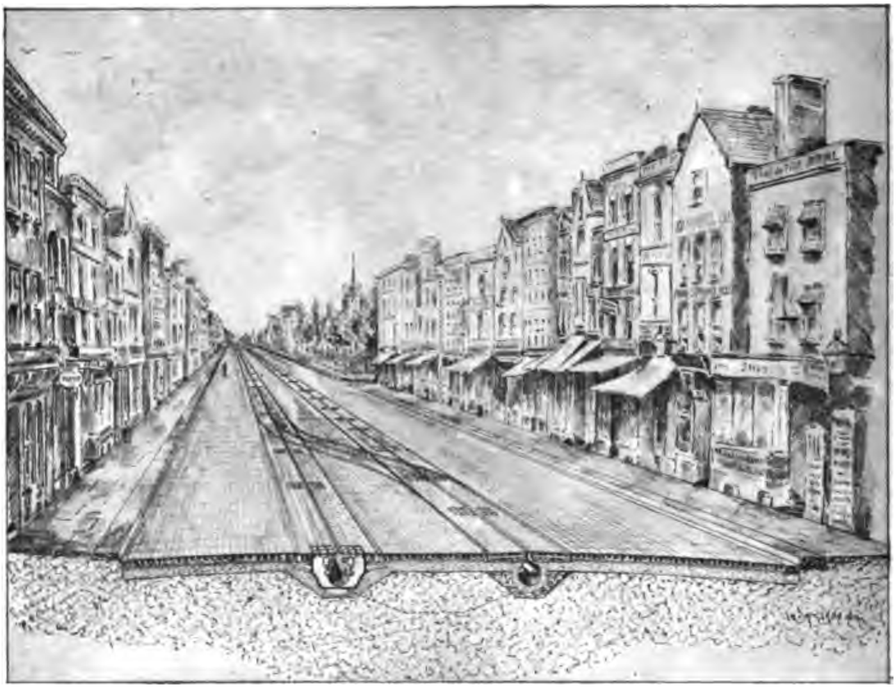


Fig. 122.—Conduit System

The cast-iron yokes are spaced 5 feet apart, the depth from the top of the slot rail to the bottom of conduit tube being 1 foot 9½ inches, and to the base of the yoke where it bears on the concrete, 2 feet 1½ inch. The greatest width of the yoke measured across the track is 26 inches, and the section at the bottom is as shown in Fig. 125. The conduit tube is of concrete.

The covers over the insulator pits give an opening 1 foot square, and will be filled in with artificial granite, or whatever material is used as paving between the track rails.

Wherever the conduit is drained a larger box, with opening 19 by 12 inches, gives access to both insulator and drain pit, and a similar size of box will be employed wherever a section insulator is used, the conductor tees being divided into lengths of about half a mile.

It will be gathered from this brief description of a conduit system that the cost is enormous compared with the trolley system, but its adoption in some city districts is imperative. The trolley system is an undoubted success, but it offers too much obstruction in the central districts of London, New York, and Paris.

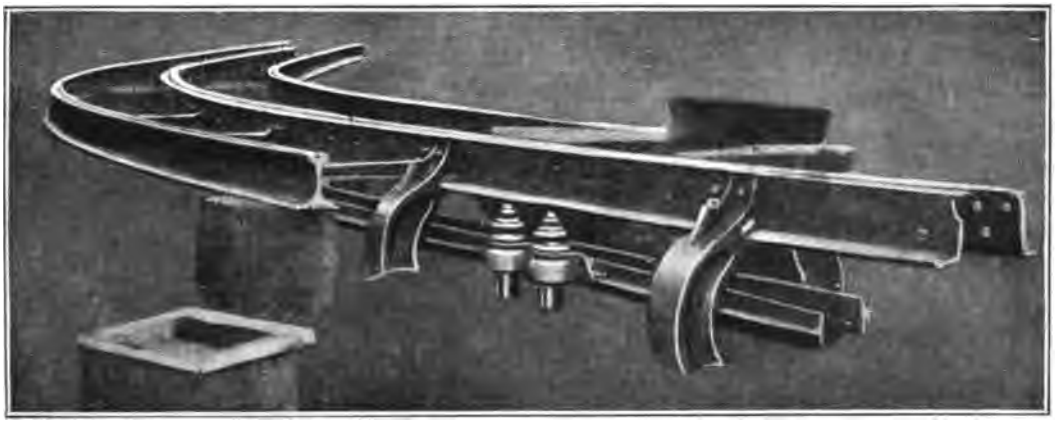


FIG. 123.—Tramway Conduit

For ordinary street trams the overhead trolley has the whole field to itself; the design is of course well known, and can be seen almost in every town. Fig. 126 shows the general appearance of a trolley system.

But now it is generally set up with only one line of poles, with a long overhanging arm carrying both up and down wires.

The overhead trolley system is the one which is almost universally used for tramways and light railways, and it is very doubtful if engineers would ever install any other system, except under special circumstances. Where such has been the case, however, it will usually be found that the reason why the overhead system was not employed, was because the city authorities would not grant permission to erect overhead wires.

There are few real objections which can be urged against this system. Many people object to the trolley wire on the ground of its appearance, but this is a matter which is generally remedied by use and familiarity.

It lacks one advantage of the conduit system, viz. the insulated return circuit, and special care in the bonding of the track is consequently necessary. Of course it would be quite possible to have an insulated return circuit overhead, but the additional trouble and expense of double trolley wires would completely swamp any slight advantage which might be gained therefrom.

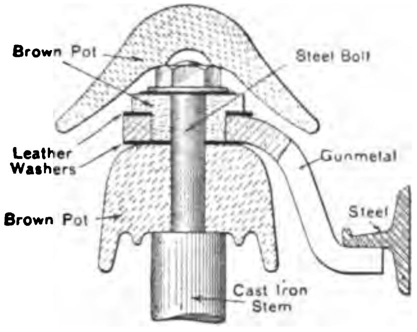


FIG. 124.—Underground Insulator

The real objection to the overhead wire is that there is always a possibility of its breakage and fall. This, however, is a most infrequent event, and there are numerous safety devices to prevent the possibility of any serious accident should such a thing happen. On the other hand, the system has considerable advantages. It is much cheaper than conduit construction, and putting down the line does not cause nearly such disturbance in the streets. All the insulators, &c., are visible and accessible, thus facilitating and cheapening repairs and maintenance.

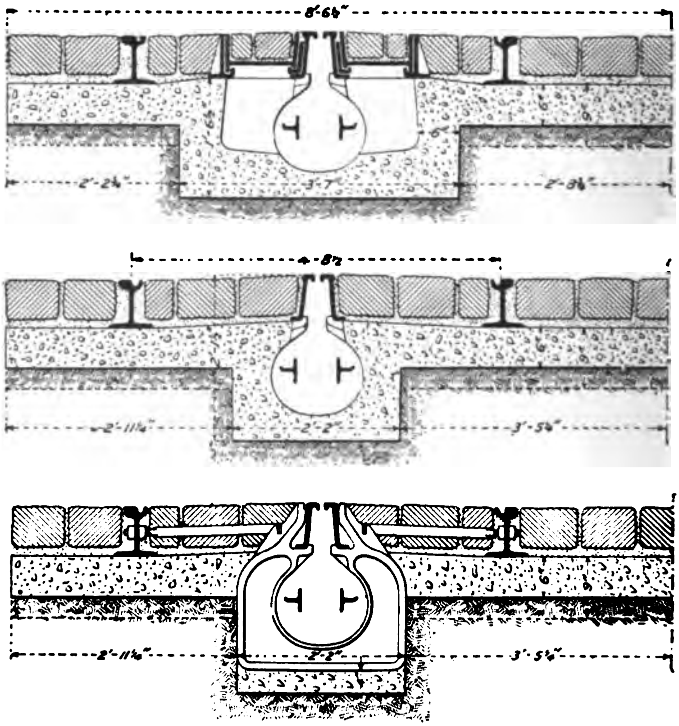


FIG. 125.—Conduit Sections

The current is gathered from the overhead wires by a bronze or copper pulley carried in a swivelling head on the end of the pole, and insulated from the pole by an india-rubber sleeve, shown in Fig. 127, as shown by the G.E. Co. of Manchester.

Overhead Trolley System

This trolley head embodies all the latest improvements, and includes a self-oiling arrangement, consisting of a hardened hollow steel spindle, with a slot cut through on the bottom. The spindle is filled with grease, and will run for six weeks without attention.

The method of insulation employed provides absolute security. It is in the form of a rubber sleeve, in one piece, and can be readily fixed by unskilled labour. The weight of the head is reduced to a minimum. The bearing surfaces are the largest obtainable, and are provided with an adjustment which can be regulated to $\frac{1}{64}$ of an inch.

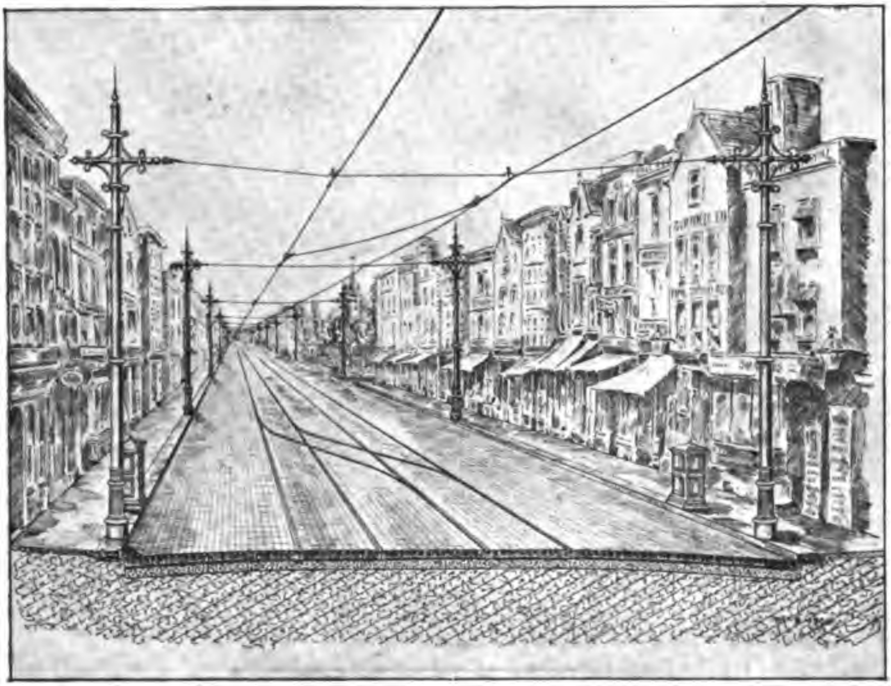


Fig. 126.—Overhead Trolley System

The thrust from the wire is taken on a hardened steel washer, an arrangement which has been found necessary to all swivelling trolley heads, and has been adopted by leading lines in Great Britain and on the Continent.

The heads are supplied with ball bearing if desired.

The full page illustration, Fig. 128, represents Mr. Blackwell's special trolleypoles and wheels. The complete pole shown has outside springs, the sectional pole has internal springs to keep the pole up to the wire. The standards are required only on double deck cars; for single deck cars the trolling arm is fixed direct to the roof on a swivelling frame, as shown in the Boston pivotal trolley. The

G.E. Co.'s, of Manchester, standard for double deck cars is shown in Fig. 129. This standard has a patent compensating lever, by which the upward pressure of the trolley decreases as the pole is brought down towards the horizontal, an advantage where the wires dip under bridges or viaducts. And it effects a great saving in wheels and heads, and also on the overhead wires.

When the spring is adjusted to give 20 lbs. pressure on the trolley wire under normal conditions, this device will be found to give an upward pressure of 12 lbs. only when the pole is brought to a horizontal position.

In Fig. 129 the cap of the standard is shown cut away to disclose the mode of action of the arrangement of the fulcrum of the lever, and a portion of the tube has been taken out to expose the spring.

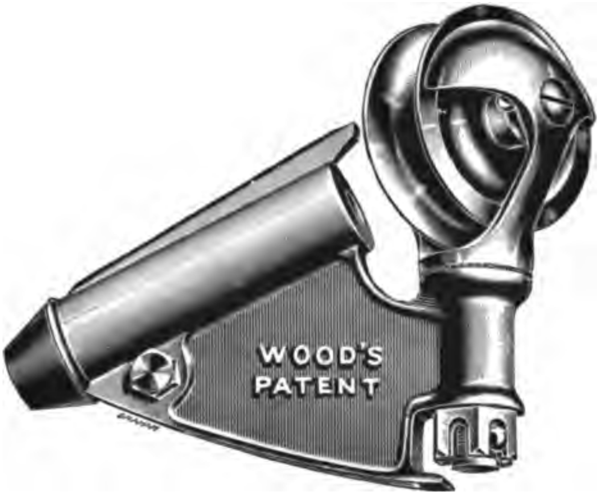


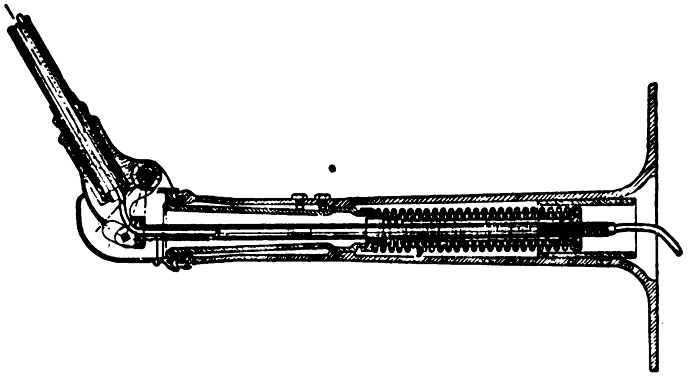
FIG. 127.—Trolley Wheel

When the danger of falling trolley wires is now well known, the safety device of this firm is also well worthy of notice. It is shown in Fig. 130.

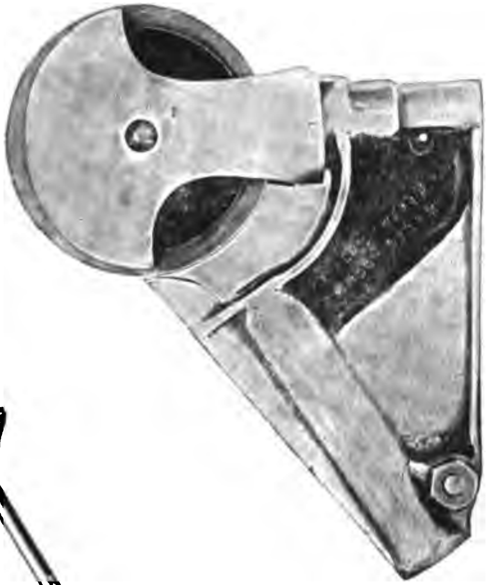
This is a device for automatically breaking the circuit when the trolley wire breaks or falls to the ground, and ensures absolute safety from any of the dangers arising from such fall.

The method of suspension employed is as follows: A continuous trolley wire is not used. Each span of the trolley wire is distinct in itself, the only electrical connection being made through the special ear which is employed. This ear is in two pieces, separately hinged, which are free to swing apart, except while there is tension on the trolley wire. The arrangement is such that so long as there is tension on the trolley wire the two pieces are in line, and the

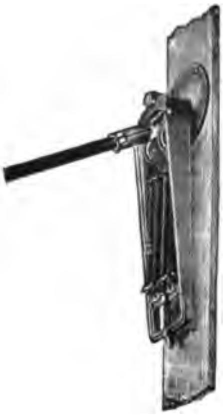
Overhead Trolley System



Latest Enclosed Spring Trolley, Patented

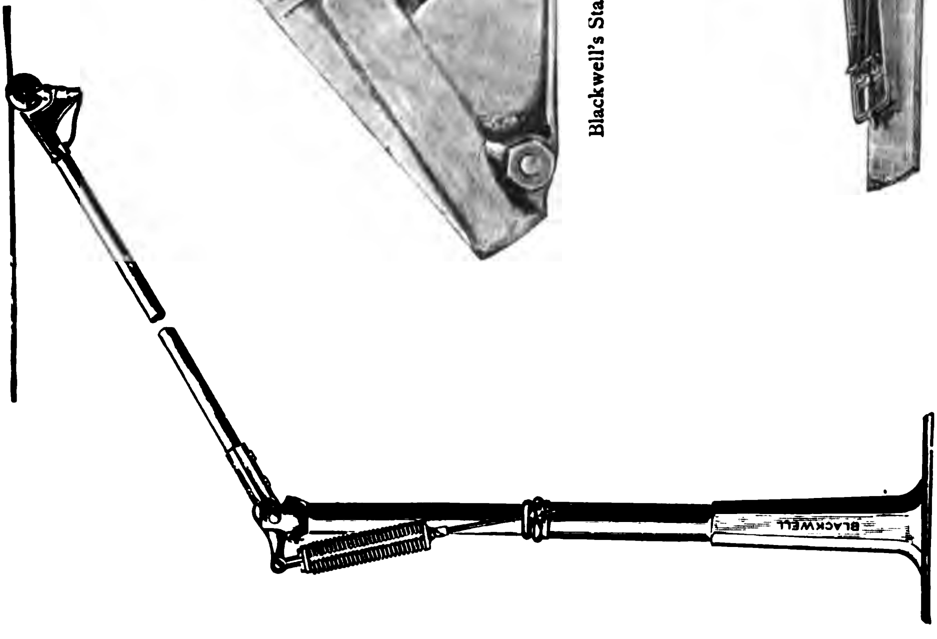


Blackwell's Standard Trolley Head



The Boston Pivotal Trolley

FIG. 128.



Outside Spring Trolley

electrical connection is perfect between the pieces. Immediately this tension ceases from breakage or any accident involving the fall of the wire, electrical connection is broken by one section. Thus the trolley wire ceases to be a live wire before it reaches the ground. From the trolley wire the current runs down to the controller, by means of which the driver of the car starts, stops, and controls the movements of the car.

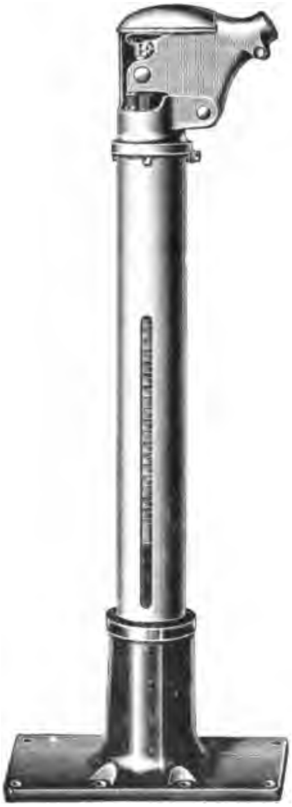


FIG. 129.—Trolley Standard

The B.T.H. Co.'s controller is shown in Figs. 131 and 132 for working the motors in series or parallel. By connecting the two motors on a car in series, each works at half the line voltage. When sufficient speed is obtained by this reduced voltage, a great saving in energy is obtained compared with reducing speed by resistances.

There is also an advantage both in economy of energy and in gradual starting by the use of this arrangement. It follows that the most saving is effected by the controllers on those roads where the cars have to run at continuous slow speed over certain sections, or where they have to make frequent stops.

The least saving is effected under conditions where the parallel connections are used entirely, that is to say, where the cars run at high speeds with infrequent stops, or where the road is all up grade and down grade, with cars running at full speed up grade and with no current down grade.

The saving in power actually supplied to cars, with series parallel control, varies from 20 per cent. to 30 per cent. in average cases. The output required from the station is diminished in a still greater proportion, since the lessened consumption at the cars in turn diminishes the drop on the line and in the track. The power demands on the station are steadier, there is less liability of overload, and the station can be run nearer to its full and most economical capacity. All these conditions contribute to diminish the coal consumption.

Current at 500 volts must be broken thousands of times each day between the controller contacts, and when in operation the apparatus is subjected continuously to mechanical shocks and electrical stresses.

The only practical and economical method of breaking the arc, formed at the finger contacts on interrupting the circuit, is that employing the magnetic blow-out, which latter extinguishes the arc as soon as it is formed, thus preventing wear and tear of the contacts. The magnetic blow-out device in its application to controllers is covered by fundamental patents owned by the British Thomson-Houston Company. The resistance of the blow-out coil is very small compared with that of the car wiring circuit, whereas on the other hand any elaborate system of numerous contacts in series, the only suggested makeshift for the magnetic blow-out, cannot fail to introduce resistance and more complication than the simple and effective magnetic blow-out device. There is no practical difference in the inductive effect upon the motors, with a given current and voltage, whether the arc be elongated to the breaking point by a magnetic field, or by a great subdivision of the arc, as when numerous contacts in series are employed.

For the purpose of giving better control of an electric car, particularly in an emergency, various methods of increasing the leverage of the ordinary hand brake have been employed.

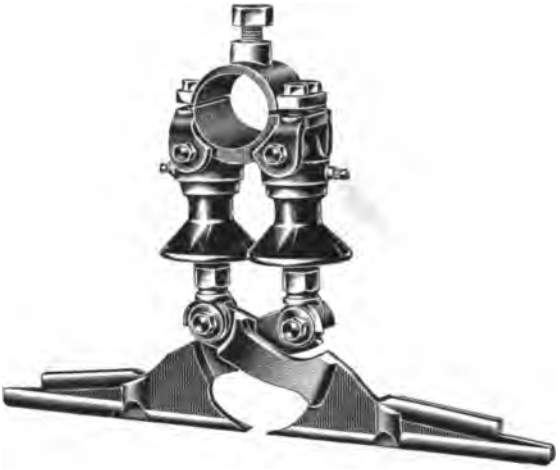


FIG. 130.—Safety Suspender

These devices, including the air brake system, are inherently defective in that the great leverage employed frequently results in setting the brakes so hard as to cause "skidding" of the wheels, thereby reducing the effectiveness of the braking.

The ordinary hand brake, almost universally employed, requires considerable time to apply, and exceptional skill is necessary to stop within three or four car lengths if running at moderate speeds; and, considering the conditions under which an electric tramcar is operated, mechanical methods of braking are inadequate when a quick or emergency stop is demanded.

An ideal emergency brake is one that can be instantly applied, and while normally holding the wheels at nearly the point of slipping, will automatically release should the wheels commence to skid, thereby stopping the car in the shortest possible time and distance.

Series parallel controllers can be operated so as to produce a quick or emergency stop by reversing the motors, tripping the circuit-breaker, and turning the power handle to the full speed point. To make a quick or emergency stop, the reversing handle is simply set to a position one notch back of the usual reversing position.

The handle is fitted with a latch which automatically locks it in either of the emergency positions, until intentionally released. This prevents the switch being accidentally opened by the motorman before the car is stopped.

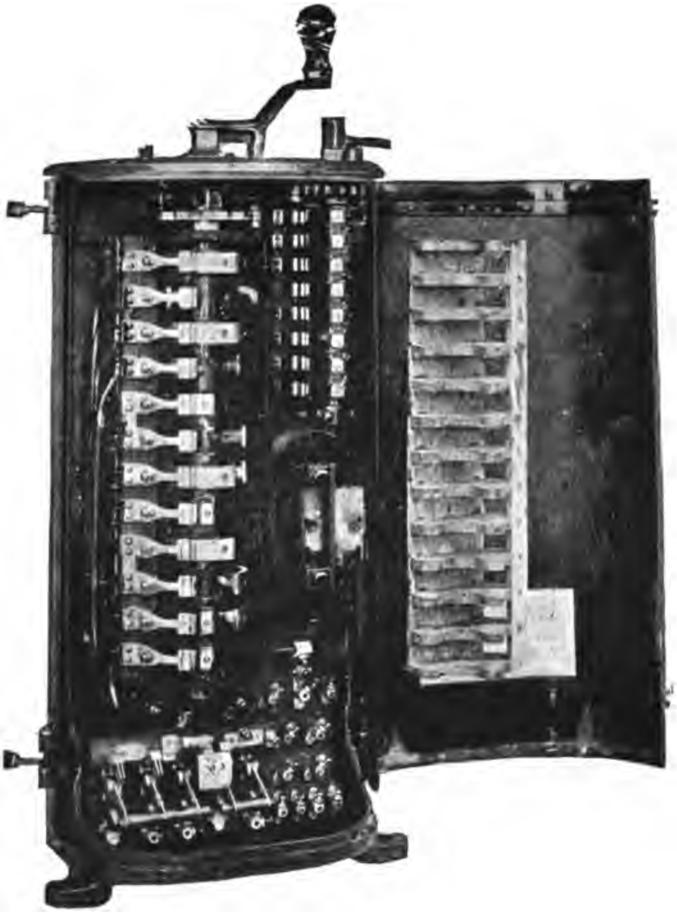
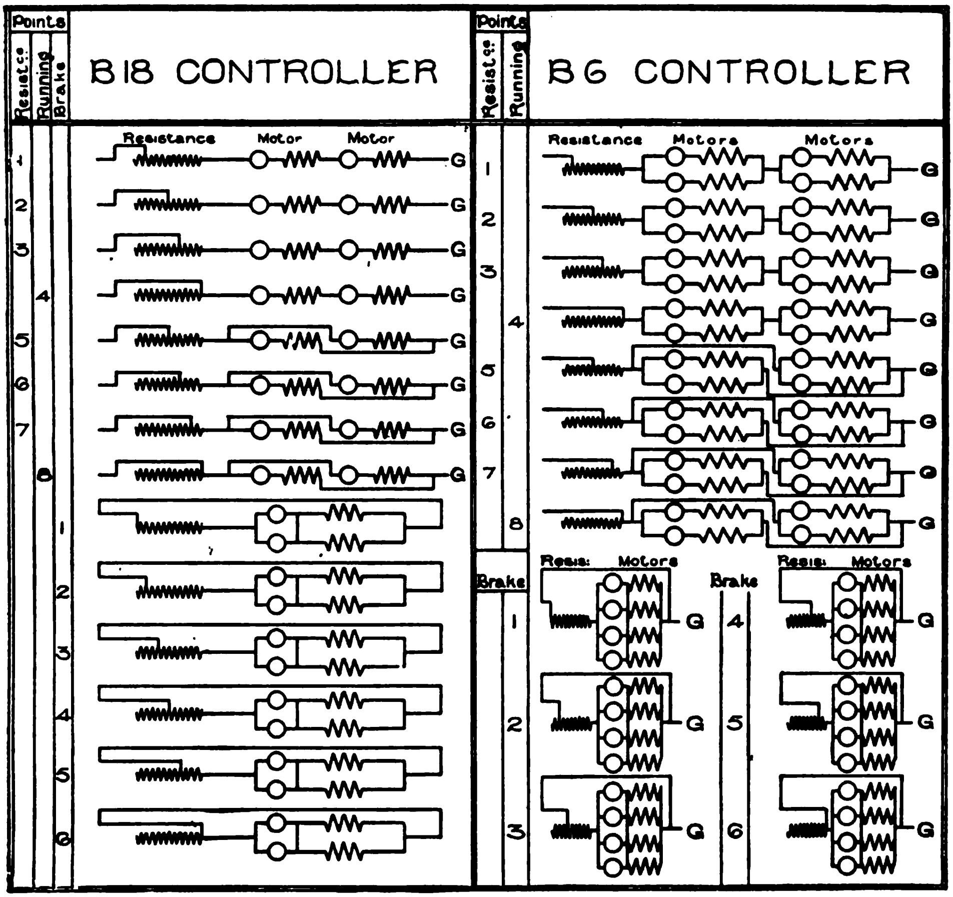


FIG. 131.—Car Controller

The emergency stop is arranged so that it may be operated with the car running either backward or forward, and is also operative in case either motor is cut out, although to a lesser degree in consequence of the retarding forces acting on only one motor armature instead of two.

The operation of an emergency stop, such as described, in no way interferes with existing brake mechanism, and it is not intended as a substitute for the regular hand brake. It is *not* a *brake*, but an *emergency stop.* It should be used *only* in an emergency, where the ordinary method of braking cannot be depended upon to act with sufficient promptness.

The question of electric car brakes is an important one, and the need for simple but effective brakes is generally recognised, and many exceedingly crude and impracticable brakes have been proposed, generally by people who are neither mechanical nor electrical engineers; so that they, how ever ingenious, are not calculated to meet the case in practice. The mechanical genius goes in for air brakes with all their complications. The electrical genius worries over magnetic appliances. The electro-magnetic brake is by far the simplest and best, along with a hand brake for ordinary use; but a hand brake in itself can never be quick enough for emergency work.



B.T.H. MOTOR COMBINATION B 18 AND B 6.

FIG. 132.

Electric Car Slipper Brake

The general construction of the Westinghouse magnetic brake for tramcars is shown clearly in Fig. 133. It consists essentially of a horse-shoe electro-magnet, M, suspended by springs from the car frame. The poles, N, S, hang downwards immediately over the track rail head. The magnet is connected by an arrangement of levers with the brake blocks of the wheels on either side of the magnet. This practically forms the whole of the brake mechanism, and it is evident that it is neither very heavy nor cumbersome, nor is it at all fragile or delicate in any detail. The brake is applied by moving the lever of the car controller backwards beyond the "off" position; thus the brake cannot be applied while the car motors are receiving current. The supply current is cut off the motors by bringing the controller lever round to the "off" position; continuing the motion of the lever beyond this position arranges the connections so that the current given out by the car motors, now running as generators driven by the momentum of the car, is caused to excite the electro-magnet of the brake. A series of definite steps is arranged for the backward motion of the controller handle whereby the strength of the current round the brake magnet may be varied at the will of the driver, suitable resistances being placed in circuit with the brake magnet coil at each step of the controller handle. The effect of exciting the brake magnet is to cause it to be drawn down to the track rail beneath. A track braking is thus secured, which is variable in intensity at the will of the driver, and which does not depend upon the weight of the car, nor does its application reduce the effective weight of the car, or the grip of the wheels on the rails. The drag of the electro-magnet on the track rail is taken up through the system of levers by increased pressure on the brake blocks of the wheel rims. The braking effects on the track and wheel rims respectively can

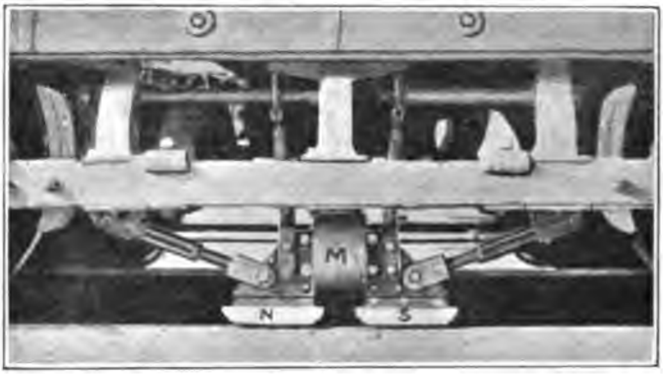


Fig. 133.—Electric Car Brake, Westinghouse

be adjusted proportionally to give the best results, that is, to allow for the maximum wheel-braking effect without skidding. These adjustments are required owing to the different types and weights of cars in use, and because of the excessive gradients on some lines. In addition to these two braking effects, there is the one which is occasioned by loading the car motors as generators. This brake is adapted for slow stops as required in normal service, and also for the most rapid emergency stops ever likely to be required. It will be seen that the higher the car speed at braking, the greater will be the emergency braking effect. The action of the brake is identical for either direction of car running, no changes whatever being necessary when the car direction changes from forward to backward.

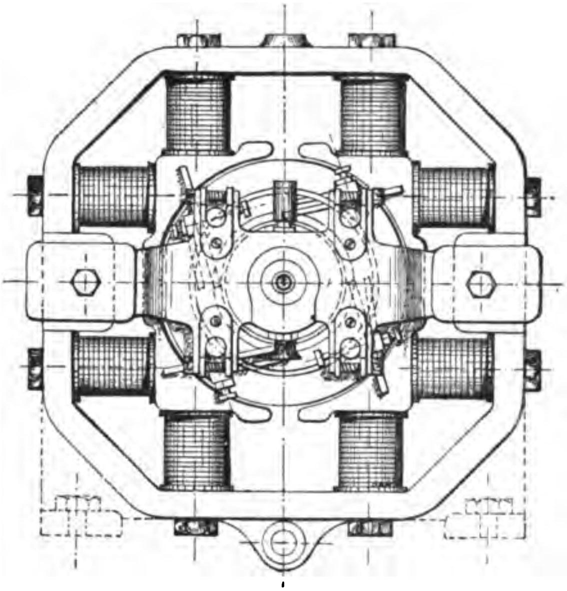


Fig. 134.—Gramme 1874 Multipolar

Fig. 132 is a diagram showing the combinations of the motors, resistances, and circuits made by the controller of Thomson-Houston, B6, described as follows for four motors :—

B6	Four 30-H.P. Four 15-H.P.	500 220	4 series 4 parallel 6 brake	1 power and brake 1 reverse	Similar to B3, but has reversible switch and brake contacts for four motors.

Also B18, a controller for two motors, described as under :—

B18	Two 35-H.P. Two 17-H.P.	500 220	4 series 4 parallel 6 brake	1 power and brake 1 reverse	Similar to B3, but connection board is so arranged that controller may be used on grounded or metallic circuit.

The course pursued by the current is through the motors, the armatures of which are shown as circles in controller diagram above the field coils as wide spirals, and resistances as small, close spirals, straight lines as connecting conductors.

The motors are ironclad, that is, the yokes of the magnets form an outer covering with enclosed ends; in fact, it is a four-pole machine with inward projecting poles, now the fashionable type of motors among engineers. It may interest some of the younger engineers to know that M. Gramme made a four-pole motor with outer iron yokes, only requiring two end covers clapped on to make the fashionable motor of 1903. Gramme's motor was made in 1874, or about *thirty years ago,* and yet we hear it declared that electricity is in its infancy. This old motor is shown here in Fig. 134.

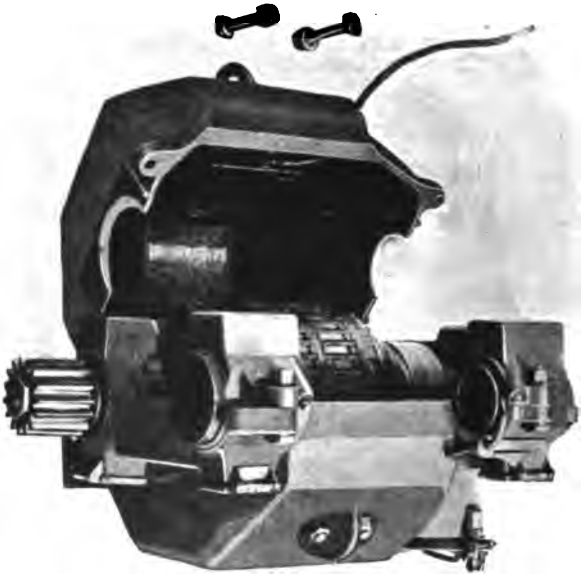


FIG. 135.—Geared Electric Car Motor

The modern improved form is shown in Fig. 134, partly open and in Fig. 135, closed.

The magnet frame is hexagonal with well rounded corners, and is cast in two pieces from soft steel of high magnetic permeability.

The two castings are bolted together, and hinged in order to allow the lower frame to swing down so as to permit inspection or cleaning.

An opening over the commutator permits inspection of the commutator and brushes, and the removal of the brush-holder yoke and brush-holders. The cover, which is of malleable iron, is held in place by an adjustable cam locking device, and can be readily removed when necessary. A small opening in the lower frame directly beneath the commutator provides for the removal of any foreign substance which may find lodgment there.

The pole pieces are built up of thin soft iron laminations, riveted together, and are held in place by through bolts secured by nuts on the outside of the frame.

The four field coils are placed at an angle of 45° with the horizontal, and are held in place by pressed steel flanges or spool holders, which are clamped to the pole pieces. The coils are wound with asbestos cotton covered wire, and when completed are further insulated with wrappings of varnished cloth and tape. The insulation on the coils is subjected to a high potential test of 4000 volts alternating current.

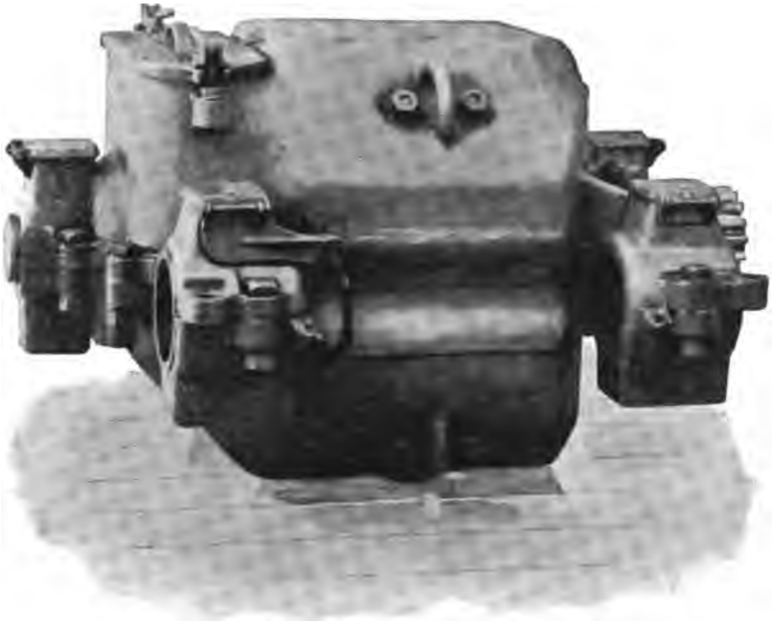


Fig. 136.—Traction Motors

The armature is of the ironclad type, the core being built up of thin soft iron laminations, which are carefully japanned and securely keyed to the shaft. The laminations are clamped at each end by cast-iron heads, also keyed to the shaft. The core is hollow, and is ventilated by the air which enters the pinion end of the core head and passes out through the air ducts between the laminations.

The standard armature winding is of the series drum type with 111 coils, the number of turns depending on the requirements of each case. The coils are made up in sets of three wires in each, in formers thoroughly insulated and laid into the slot.

The commutator has 111 hard-drawn copper segments, insulated with carefully selected mica, and securely clamped to a malleable iron shell. The segments are slotted at the back to receive the commutator leads. The diameter of the commutator is 9⅛ inches and the wearing length 3⅛ inches, with a depth of 1 inch, measured at the front end. The cone clamping insulation is of the best quality of mica, built up and pressed hard and compact. The mica between the segments is of a somewhat softer quality, in order that it may wear down evenly with the segments.

After the commutator is completed, the insulation between the segments and the shell is subjected to a high potential test of 4000 volts alternating current, and the insulation between adjacent segments 400 volts.

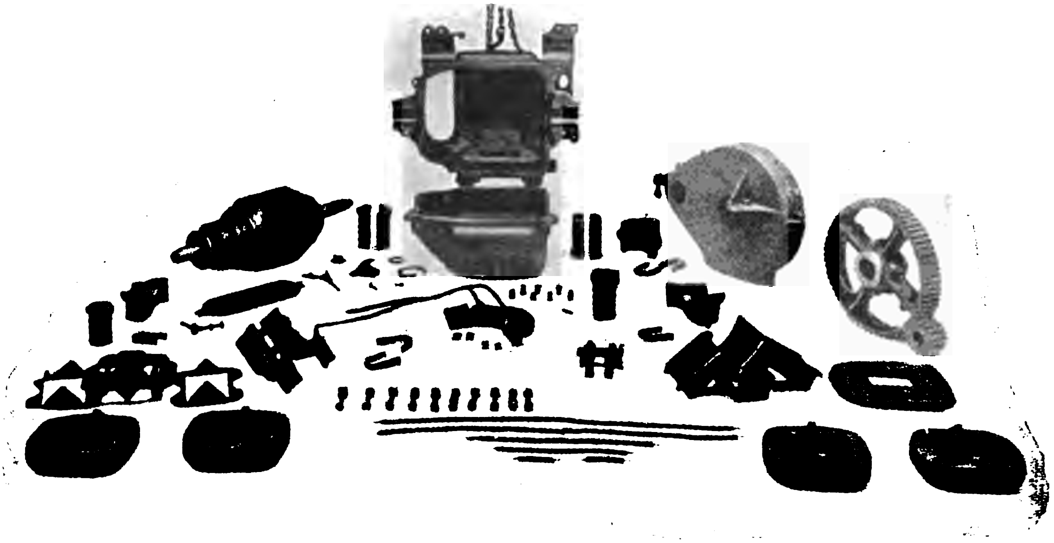


FIG. 137.—Parts of a Four-Pole Traction Motor

The two brush-holders are of cast brass. The brushes slide in finished ways, and are pressed against the commutator by independent pressure fingers, which give a practically uniform pressure throughout the working range of the brushes. The brush-holders are clamped to a hard wood yoke, which is bolted to the top of the magnet frame, and can be removed through the opening in the frame over the commutator.

All leads from the motor to the cables are brought out through rubber-bushed holes in the magnet frame at the front of the motor.

Fig. 137 shows all the parts of a B.T.H. motor taken apart and laid out.

A four-pole motor, having two salient and two consequent poles, was placed on the market ten years ago and met with great success on the continental and British tramways, and may be described as follows: The pole pieces are cast as part of the frame, and the field coils are secured in place around them by means of removable flanges. The field coils have been designed with special attention to thorough insulation. Care is taken in the selection of the materials, tests being made with samples of all wire, paper, cloth and tape used in their manufacture. Equal precaution is maintained in the winding of the coils and in the application of the insulating material. The field coils are wound with asbestos covered wire, and covered with varnished cloth and tape, and then immersed in japan and afterwards baked. This construction results in a so-called "mummified" coil, which is impervious to moisture, protected from mechanical injury, and capable of withstanding such excessive temperatures as may result from overloading. It is therefore well fitted to render long service under the exacting conditions imposed in tramway work.

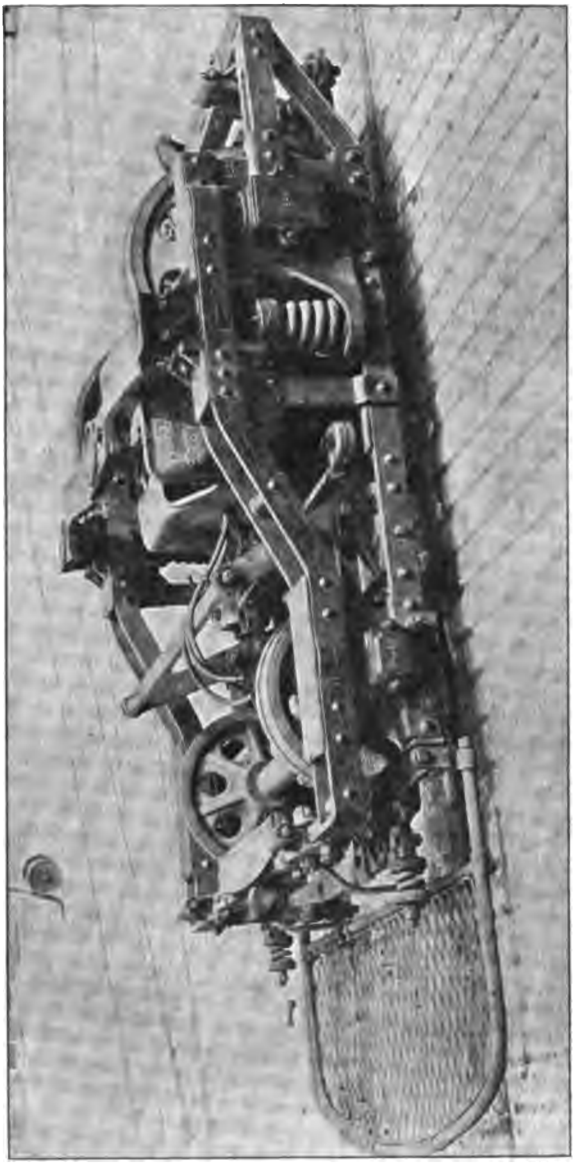


FIG. 138.—Car Truck fitted with Motor

The armature is of the slotted or ironclad type. The discs forming the core are first punched from annealed iron, then again annealed and japanned. The second annealing after punching insures a low core loss by removing the hardening effect of the punching. The discs are then built up on the shaft, after which the slots in the core are carefully prepared for the insertion of the armature coils.

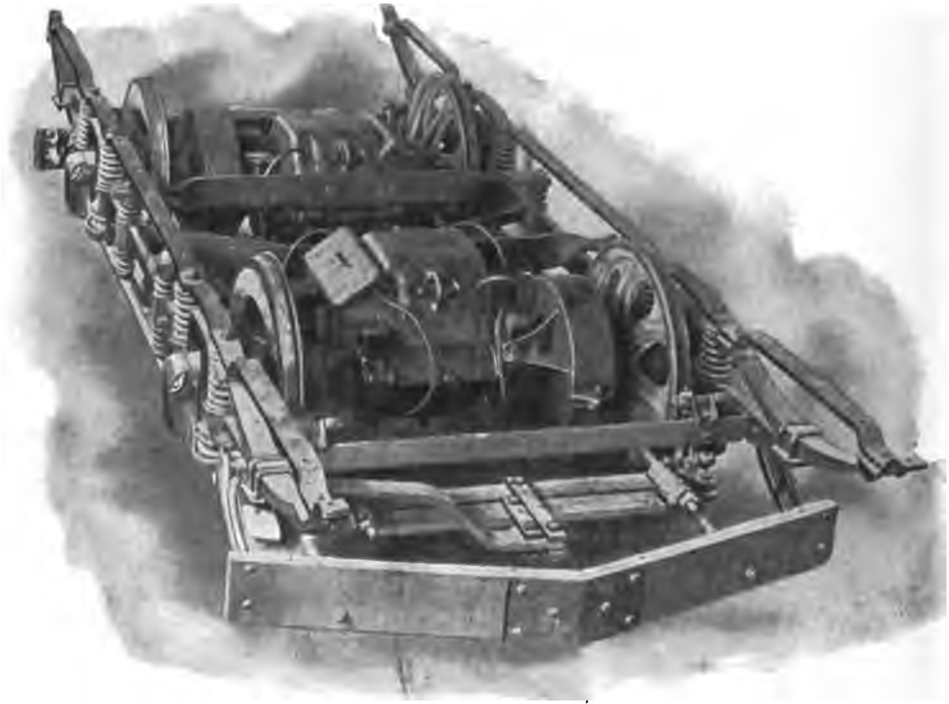


FIG. 139.—Car Truck fitted with two Motors

Fig. 138 shows this motor fitted in the truck of a two-motor car ready for the car

The four-pole motor with two salient and two consequent poles ironclad was first designed and made by the author of this work in 1886. See Professor S. P. Thomson's 1888 edition of "Dynamo Electric Machinery," p. 183.

Fig. 139 is an illustration of the whole under gear of a tram-car driven by two electric motors, with single reduction gear by the Johnson-Lundell Company. All the gearing is entirely independent of the car, and all the springs are on the truck, so that any car body can be fixed on top. This sound and sensible practice, followed by skilled trained engineers, compares very favourably with the practice of motor road car engineers, who have not yet evolved a good design for a truck, or, as they prefer to call it, a "Chasis."

These details apply to all traction work. And now a word about the adoption of electric traction in various places may be interesting.

Electric street railways were bound to be immensely popular and very profitable. For decades the working people required rapid and cheap transit in towns; formerly the workers huddled together near their work, and hence the horribly overcrowded slums in the very centres of civilised communities. The municipal tramway is destined to alter this state of affairs, in fact has already altered it, in those towns where it has for some years been in use, by opening up suburban workmen's dwellings. Without being accused of socialism, one might suggest that municipalities should purchase land cheap in the suburbs of cities, and connect it with an electric tramways, and offer it for sale for workmen's dwellings only. The electric tramway, by spreading out the population, will play a larger part in relieving some social difficulties than ever did the telegraph, steam railway, or steamboat.

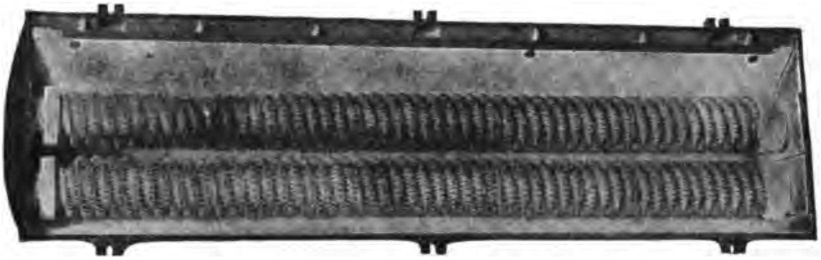


FIG. 140.—Electric Heater for Cars

But the electric tramway is also used by the better-off classes to a large extent. The cars are speedy, clean, and spacious. The only fault in them, one perhaps peculiar to districts, is want of ventilation in cold weather, especially in Yorkshire, where people are allowed standing room inside, three rows, eleven on each side sitting, and eight up the middle passage standing, all boxed up like sardines in air-tight cases. The fear of a cold draught is much stronger than the disgust for foul air in these parts.

The heating of electric cars by electric heaters to some extent alleviates this trouble, for if the tramcar is heated inside by electricity, the air is not consumed as it would be by oil or coke stoves.

Fig. 140 shows such an electric heater, consisting of spirals of resistance wires encased in a perforated protector. The heat can be regulated by a simple switch.

Then the subterranean or underground railway is another case where electric traction has no rival worthy of consideration.

Ventilation of the London electric tubes has also been a difficulty, and requires some more intelligent treatment than hitherto it has received. The ventilation of these tubes is a problem to be solved somewhat on the same lines as is the ventilation of coal mines carried out by mining engineers.

It requires no profound electrical engineering knowledge to see the advantages of electrically transmitted power to the street cars and underground cars. And perhaps the same may be said to its application on overhead railways in towns.

But there its competence ends. The idea of transmitting the power to railway trains of heavy weight, high speed, and on long journeys, is an ambitious one, but one at present held only by those who know nothing of the mechanical difficulties yet to be solved before it could be practicable and profitable.

Railways, no doubt, could with profit work frequent trains on suburban traffic by electricity, and also short branch lines, and these for a long time to come are the only applications practicable on surface railway systems. The talk of "electrifying" the main lines is only the bombast of electrical engineers with a "system" and their allied company promoters.

Overhead suspended electrical railways have from time to time been brought forward, since the early days of Telpherage, in which goods were carried in skeps suspended from little motors running or creeping along the overhead trolley wires; the trolley wires were of 1-inch steel rods, and required heavy supports, for it carried the whole moving weight.

Inventors have continually tried to evolve a railway differing from the common surface track for short lines—something which could be established without earthworks. One of the latest proposals comes from Russia, by Mr. H. W. Romanoff, and is described in the *Electrical Review* of London. Fig. 141 shows a bend in the line with the car coming round, which was a short time ago laid down for the Emperor of Russia on the system of Mr. H. W. Romanoff. The line is only 700 yards in length, and is laid from the Emperor's palace to the Gatchina railway station. It derives additional interest from the fact that the system has been occupying the attention of the Russian Minister of the Interior (Home Office), who has appointed a commission to inquire into its adaptability for a line between St. Petersburg and Moscow.

Mr. Romanoff's system has one feature in common with those of Langen & Enos, *i.e.* the suspension of cars from the rail, and surrounding it so that they cannot jump from the rails without breakage of several parts simultaneously; but these are said to be the only points of similarity.

In Romanoff's system the permanent way consists of girders cross-joined holding the rail, strengthened by an iron belt serving as a foundation for the rail. The only points to consider are the sizes and dimensions of the car. At present Romanoff uses T-shaped standards, supporting double tracks, but there is nothing to prevent him from making a single track with passing places. The biggest incline on the short railway in Gatchina was .018, and the smallest curve of 35 feet radius. The weight of the railway depends, of course, on the weight of the car; for military purposes 75 tons per mile is sufficient, but for passenger purposes it is from 260 to 400 tons per mile.

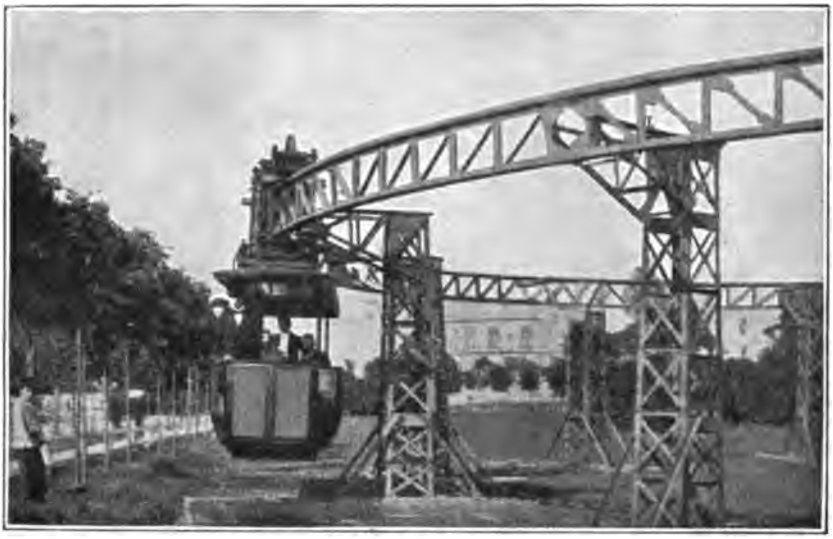


FIG. 141.—Romanoff Electric Traction System

This system is divided by Romanoff into different types :—

1. The main line railway for heavy traffic and high speed, *i.e.* 120 miles and over.

2. For high-level town traffic without impeding the ordinary street traffic.

3. For military portable railways or for other purposes, such as mining and light goods traffic.

4. For postage purposes, light parcel and express letter cars, which require a very cheap and very light line, and travel at 150 miles per hour.

An estimate has been made of the cost of a railway such as that proposed from St. Petersburg to Moscow, 345 miles long, with 66 trains travelling simultaneously with a speed from 90 to 108 miles per hour, including (1) the cost of construction of permanent way, (2) installation of block signal system, (3) rolling stock of 400 cars for 35 passengers each, (4) workshops and carriage sheds for repairs, (5) 40 generating stations of 1500 H.P. each, (6) signalling apparatus, (7) cottages for servants, (8) 80 high-level platforms, (9) all foundations for standards, &c. The total cost, according to the report of the Imperial Russian Technical Institute (dated 15th February 1901), is £23,800 per mile.

At high speeds the trolley wheel as a current collector fails, and is apt to jump the line, and as high speeds over long distances require much energy to propel a heavy train, Messrs. Siemens and Halske of Berlin have made many improvements to meet the requirements. They made an experimental line at Gros-Liehterfelde to work out the problems. Fig. 142 is an illustration of the experimental locomotive.

A voltage of 10,000 volts three-phase was chosen, and this is delivered directly to the locomotive, on which the current is transformed down to a low pressure and fed to the motors. The collectors are sliding bars, but vertical instead of horizontal. Thus the overhead line can be placed to one side of the track, and there is room for a guard net below it to prevent accident in case of a broken wire. The three vertical spindles supporting the sliding bars press the latter against the wire by means of the spiral springs seen in the figure, which allow for the necessary lateral motion of the collectors, while the up-and-down motion is controlled in each case by a spiral spring around the horizontal spindle on which the collector arm is fixed. The bar itself is of aluminium. On the roof are three Siemens horn-shaped lightning protectors.

The three high-pressure wires are mounted 1 metre apart, one below the other, on brackets fastened to iron lattice poles, the three-lip insulators to which the wires are actually fixed being mounted on a flexible wire suspension so contrived that the insulator slants forwards slightly. The distance of the lowest wire from the track is 5½ metres.

The 10,000-volt 50 three-phase current is led in from the collectors, conductors passing through an iron tube to the main high-voltage switch in one of the transformer chambers. There are two three-phase transformers, one at each end of the locomotive. The transformers transform down to 750 volts, and there are two asynchronous motors rated at 30 H.P. normally, and with a maximum permissible output of 120 H.P. The maximum speed of the locomotive is 60 km. per hour, and the gear ratio is 1 : 3.15. To regulate the speed a controller is provided which is externally of the usual shape, but internally quite different. The variations in the speed are effected by changing the connections of the transformer secondaries. For full speed under ordinary conditions they are connected in star, for a large tractive effort in mesh, and for half speed one of the secondary phases is left open. The contacts are provided with magnetic blow-out devices. Rheostats for putting resistance in series with the rotor on starting are, of course, also provided.

The success of this experimental line has demonstrated the possibility of employing very high pressures, and the experiments with extra high speeds have still to be made. To this end the Studiengesellschaft für Elektrische Schnellbahnen, a company formed by Messrs. Siemens and Halske and the A.E.G. for the purpose of studying these problems, ordered a car from each of the above two firms, and a trial line for a speed of 200 km. per hour has been prepared.

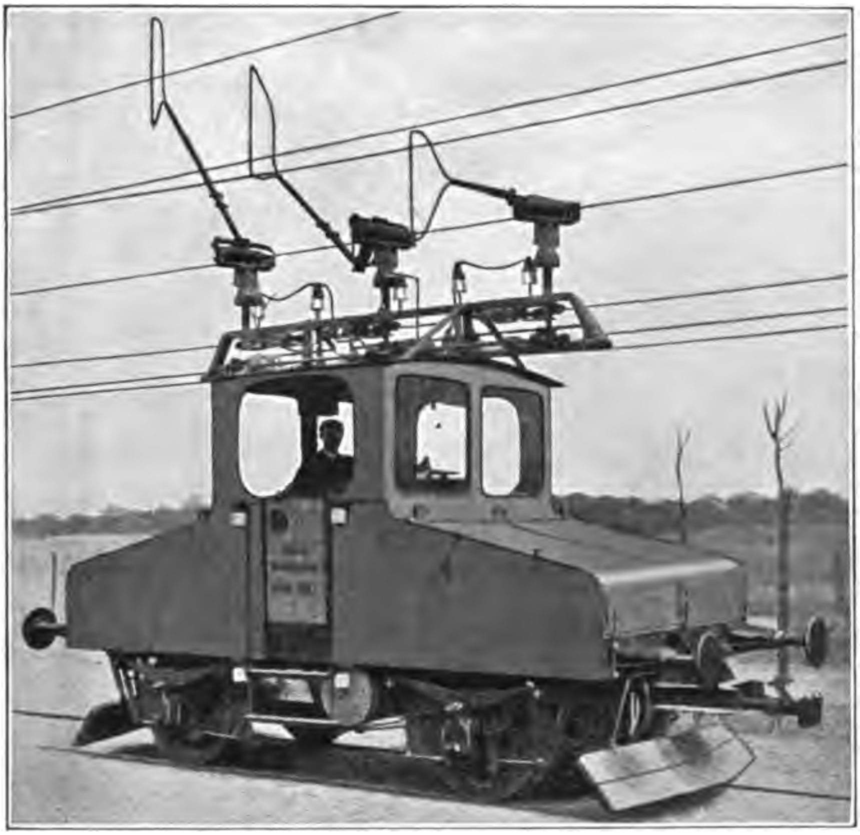


FIG. 142.—Three-Phase Traction Locomotive

This brief description of an experimental line made and used by an engineering firm, at their own expense, to solve important practical questions, is selected as an illustration of the methods of business pursued by these firms compared with British electrical engineering firms, and shows how the foreign firms prepare themselves for future business. I observed the same thing in America about fourteen years ago; two large concerns then visited had laid down short tracks of electric tramways, and had engaged experts in motors, controllers, gears, and cars, whose sole duties seemed to be to play at tramways, but they were not only perfecting details, but exhibiting their model tramways on a working scale to those capitalists who afterwards put up the money to equip the cities and towns of America with electric tramways ten years before anything was done in Britain to speak of. We cannot imagine a British firm spending money in this apparently (to them) reckless way, when as likely as not the information obtained could not be monopolised; but the foreigners do it, for although they cannot monopolise the improvements and information gained, it is a fact they have secured a monopoly of the contracts for electric traction, and that after all is the main object which they have in view.

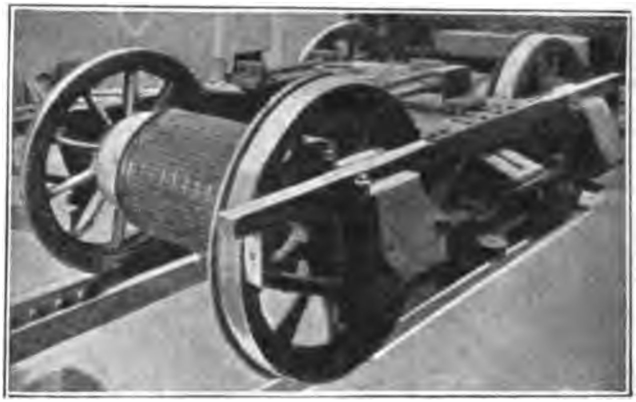


Fig. 143.—Motor Truck of Central London Railway

The Central London Railway is about the largest electric railway work in this country, and is worked by electric locomotives, each having eight wheels fitted with four 117 H.P. motors, one motor to each axle.

The motors, which are series wound for 117 H.P., are mounted directly on the axles of the locomotives, and for this purpose the armature is built up on a brass sleeve, into which the axle is afterwards forced, Figs. 143, 144. The case also forms the yoke of the magnetic circuit, and is made of high permeability soft cast steel, in two halves, so arranged that when in place the lower half can be dropped to expose the armature for examination, Fig. 145. This steel yoke has four laminated magnet cores and pole-pieces bolted to it internally, and is rigidly fixed to the bogie frame, which carries the bearings. All the magnet cores are wound, two having large coils and two small ones. The large coils, which are situated horizontally, each have 76 turns of strip copper 2.125 inches by 0.11 inch, the small ones having each 15 turns of strip copper 0.875 inch by 0.22 inch. The coils are wound on formers, and thoroughly insulated before being put in place, afterwards being held in position by brass castings bolted to the steel magnet yoke. The principal insulation used for these coils is asbestos. At full load the current density in the small coils is 1000 amperes per square inch, and in the large ones 820. The armature is built up of slotted punchings assembled directly on the brass sleeve. It has 61 slots, each 1.73 inch deep by 0.52 inch wide, and has a single circuit series drum winding. The construction is of the bar type, the conductors being 0.6 inch by 0.1 inch. There are six such conductors per slot, making in all 183 total armature turns, the current density at full load being 2100 amperes per square inch. The winding is held in place by hickory strips and steel binding wire. The magnetic density at full load in the armature teeth is 127,000 lines per square inch. The commutator is 19 inches diameter, and has 183 segments—one per turn; it is 8 inches long, and has two sets of carbon brushes—four in each set. The commutator segments are held in place by steel core-shaped rings, being insulated therefrom by mica, which are mounted directly on the previously-mentioned brass sleeve.

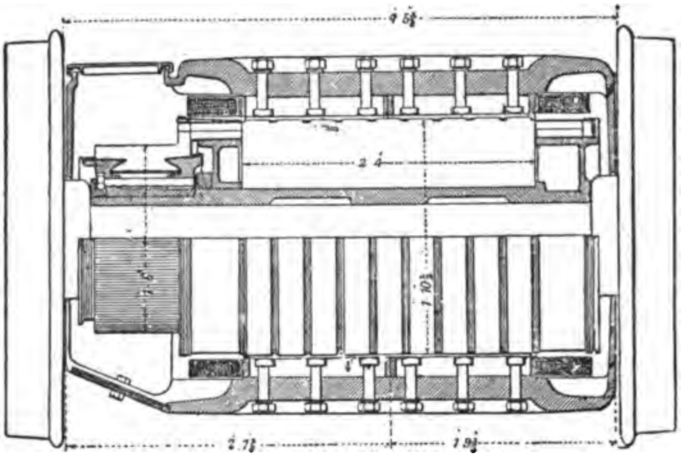


FIG. 144.—Traction Motor and Wheels of Central London Railway

Controllers.—Control of the motors is effected by the series parallel arrangement. There are two sets of two motors to be regulated, the entire operation being performed by one handle.

Westinghouse air-brakes are used. This motor is fitted with a device to start and stop automatically as the pressure of air in the reservoirs gets below or above the working mean of 80 lbs. per square inch. The reservoirs are situated close to the resistances, and warning whistles are operated from the same. The total weight of the locomotive is 97,000 lbs., and is capable of exerting a draw-bar pull of over 30,000 lbs.

Many hare-brained schemes for electric traction have been made, such as employing a series of solenoids along the line with a car or carriage like a core, which is to be pulled like a shuttle through each solenoid in succession. The subject of brakes, fenders, rails, and posts for trolleys are mechanical, and beyond our scope.

But a few words about the line and track may be of interest.

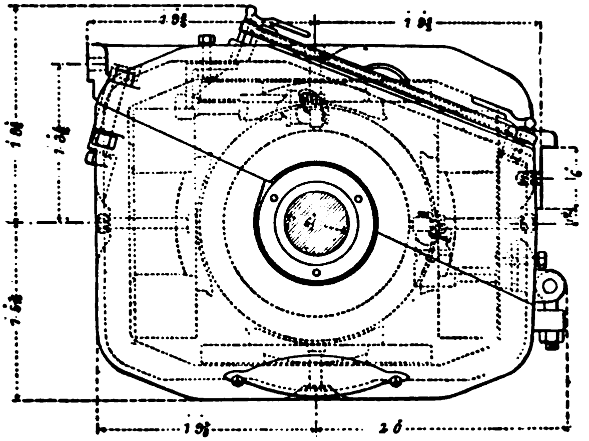


FIG. 145.—Traction Motor for Central London Railway

The trolley wire must not be less than 17 feet above the ground, the posts carrying the wire must not be more than 120 yards apart. The 17 feet is measured from the lowest point on the wire between posts.

These are arbitrary rules made by the Board of Trade for safety. The trolley wires are divided into sections of half-mile lengths, or as near that as possible, and these lengths are insulated from each other, and connected directly to a feeder laid insulated along the track.

The insulation of the trolley wire at 500 volts must not allow more than 0.01 ampere to escape from any section, so that by Ohm's law the insulation of a section should be

$$C = \frac{E}{R} \therefore \frac{1}{100} = \frac{500}{R},$$

hence R = 50,000 ohms per half mile.

As to joints in a trolley wire these should be made at posts, and specially designed and carried out.

The protection of the trolley wires by guard wires or other devices are inadequate to the purpose in many cases, but since several serious accidents the guarding of trolley wires from falling telephone and telegraph wires has received more careful attention and has been improved. Guard wires should be above the trolley wires by at least 18 inches, and should consist of two wires about 18 inches or 2 feet apart, thus •,•, where the comma is the trolley and the colons the guards.

In the case of the trolley wire breaking, automatic no load or overload switches are necessary, or some mechanical device, such as we have shown in figure to cut out the broken section from the feeders. The following is an abstract from an article in the *Electrical Review* by Mr. Donald S. Munro, A.I.E.E., who has invented a safety device against these dangers.

The nature of this device will be understood from Fig. 146. The guard wire is earthed only through the high resistance releasing coil—or a resistance and coil—of a cut-out switch placed on the

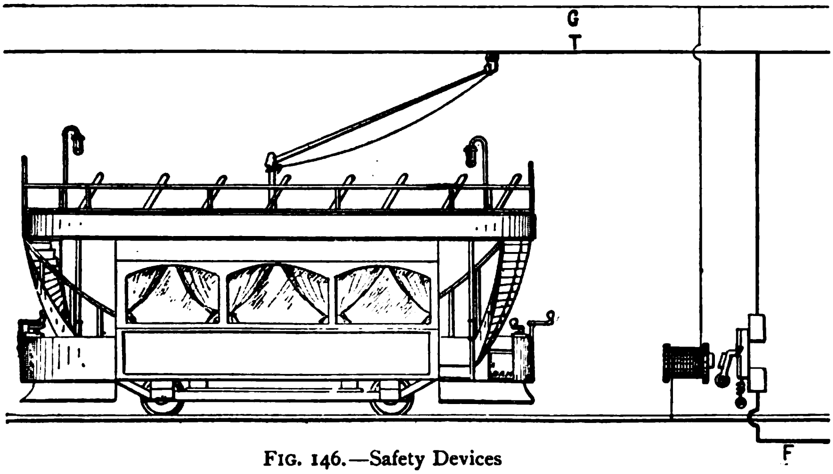


FIG. 146.—Safety Devices

feeder, in a street box, or at the station if preferred. When the guard and trolley wires are electrically conducted either by firm or by light contact, as with a fallen telephone wire, for example, a small current passes from the trolley wire along the guard wire to the high resistance coil of the cut-out, releases or actuates its automatic switch there, and so disconnects the feeder branch from the trolley section. Thus, without shock to the electrical system, the trolley wire section becomes dead until the fault is removed and the switch is restored. If the trolley wire section is fed from both ends, both ends are thus cut off, or, where routes do not permit of this, they are by like means disconnected. By this simple and inexpensive method the utmost possible degree of security is afforded against all accidents to trolley wires, except the fall and fracture of the trolley wire itself; for, perhaps, neither the falling trolley wire nor its supporting wires would be springy enough to ensure contact with the standing guard wires under those circumstances. For protection against this rarer accident some would rely upon their overload cut-outs, but to bring this form of trouble also within control of the "guard cut-out" described above, it is only necessary to provide some method of making sure of an electrical contact able to convey a very small current between the guard and trolley wires when the latter breaks.

Fig. 147 illustrates an appliance for this purpose. It is more reliable, less clumsy, and less exposed to weather troubles than others which have been suggested. It is about 3 inches long, and is hung between the guard and trolley wires, being joined to each by flexible copper cords, attached for choice at points of support which change their relative positions when the stresses are altered by fracture of one or other.

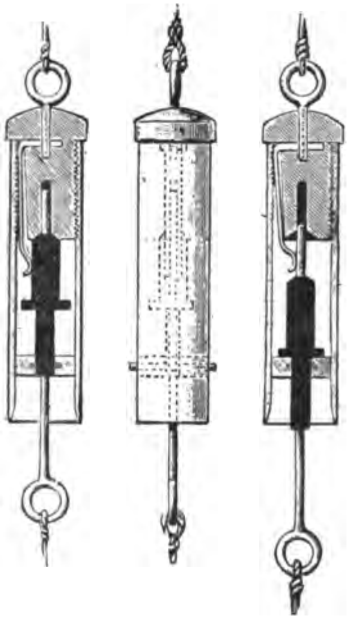


Fig. 147.—Contact Device

The well-known device invented by Mr. Quin, late of Blackpool, is on right lines so far as it goes. The switch has apparently to be reset every morning, and perhaps oftener, as it goes "off" every time the pressure becomes low, or the line is disconnected. This last objection could be obviated by fitting to it certain appliances, one arrangement of which is shown in Fig. 148. G is the guard wire; T is the trolley wire. The lines representing these are necessarily short, and the working appliances represented on a much larger scale, but each line marked G or T represents a section of any length—say, 500 yards —and connections made to either end of these short lines are to be taken as made to either end of the section. The switch apparatus may be gathered together in the generating station, or preferably in street boxes situated near the first junction of the feeder cable to the overhead trolley sections concerned. F is the feeder cable from the generating station. E is earth, rails, or return conductors, or the mid wire of a three-wire system as the case requires. P (used only in a few of the arrangements) is a pilot wire from the far end of the trolley wire. S is any suitable automatic switch, diagrammatically represented here by a pivoted or flexible armature with a detent thereon, which is, by spring or gravity, normally held so as to retain a bridging piece making contact between terminals connected to the trolley and the feeder wires respectively. The bridging piece, when released by the effective attraction of the armature by one or other of its electro-magnets, falls, or is pushed, or pulled, so as to break connection between the feeder and the trolley wires, and leave the overhead section "dead." Alternatively, but not preferably, the armature, when attracted, may put the feeder to earth, and thus melt a fuse or cause an overload cut-out at the station to go "off." In the latter case, the attracted armature, at the option of the engineer-in-charge, may, or may not, lock itself so as to keep the "earth" on until the armature is restored by hand, as a signal to the station that the line is clear. A, B represent two electro-magnet coils. In Figs. 148 and 149 either may act as circumstances determine.

The bonding of the rails is an important electrical matter where the rails are used as the return circuit. It consists of bridging across the joint between rail and rail by a good conductor, so as to provide electrical continuity. There are various methods obvious to any electrician. A simple bond is a stranded copper cable, with solid ends to screw or rivet into the rails.

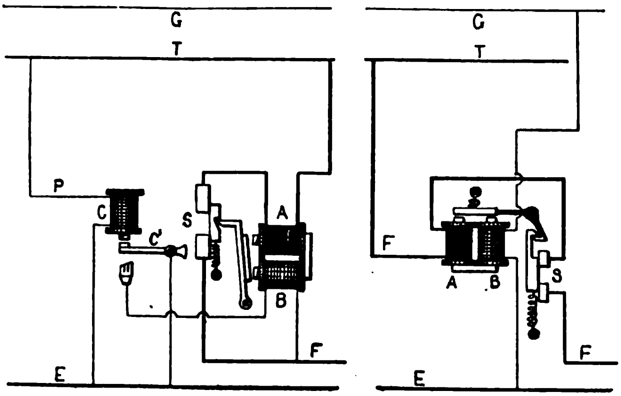


Fig. 148 Fig. 149

Safety Devices

The "protected" rail bond shown in Fig. 150 represents a good example. This rail bond is manufactured and sold by the Forest City Electric Company, 18 Piccadilly, Manchester, who have made a special study of the problem of rail bonding, and who undertake the design and manufacture of bonds to suit all cases and conditions. Their bonds generally consist of a flexible copper conductor, fused to solid copper terminals. The flexible part of the bond is composed of a number of specially drawn flat copper strips, the cross-sectional dimensions of which are .193 x .036 inch, placed parallel to each other, and in such a position in relation to the rail that any bending or vibration to which it may be subjected, due to any movement at the joint, will be in the direction of the least dimension of the strip. This construction makes an extremely elastic bond, and any distortion to which the bond may be subjected will generally be within the elastic limit of the copper. This also means a minimum amount of strain on the terminals, which is of vital importance. Crimps, or loops, are formed in the flexible part of the bond to provide for contraction or expansion of the rail. These may be inserted in any portion of the bond, varying according to the position of the bolt holes in the rail, and the position of the other bond, in case of double bonding. The bonds are fastened to the rail by expanding the solid terminals in the holes by specially designed machinery, by which extreme pressure the copper is made to flow into every minute irregularity of the hole, and a perfect mechanical, as well as electrical, joint is attained. The manufacturers of this bond recommend the use of a short bond placed under the fish-plate, thereby utilising as much of the rail as possible as a conductor, and economising copper, as well as reducing the total resistance of the joint.

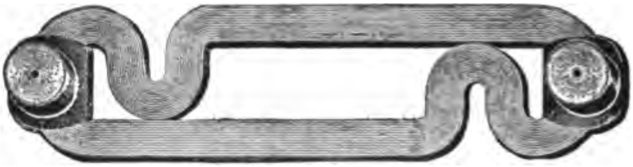


FIG. 150.—Protected Rail Bond

Fig. 151 represents the Columbia rail bond, for which the following advantages are claimed. The contact of the "Columbia" with the rail is seven times the section of the wire, providing ample contact to compensate for the poorer conductivity of the steel in the rail. The contact of rail and bond is made by a wedge expanding the thimble against the hole in the rail. This wedge is *not* driven in with a hammer as in the case of pin bonds, but is put in with a press. A press can be so set that no matter what may be the want of intelligence or care of the workman, he cannot put in the bond in any but the right way. This is considered to be a very great point.

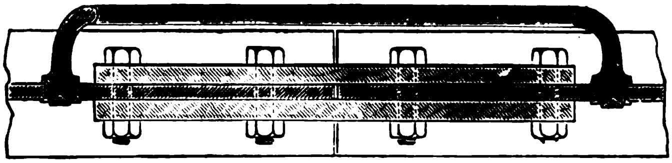


FIG. 151.—Rail Bond

As to road traction, the electrical vehicle has not made much progress. The lead accumulator in ebonite cells has far too much weight and too short a life for practical traction work. In Vol. III. we mentioned that Mr. Edison had made a new cell composed of nickel and iron with an alkaline solution. Since the publication of that volume more detailed particulars have come to hand of that new cell, and as it may prove superior for traction purposes it is described here in an abstract from the *Scientific American.*

"In the first place, the jar used is of sheet steel, corrugated to strengthen it for about two-thirds of its height. The plates fit tightly in the jar, with their vertical edges pressing against hard rubber side frames that have properly spaced grooves to receive them. They rest on four suitably-grooved hard rubber wedges, and are separated by hard rubber strips. All the hard rubber parts are shown in black in the diagram, and thus can be readily distinguished.

"The plates themselves consist of very thin sheet-steel frames, into the "windows" or slits of which are hydraulically pressed briquettes of iron and graphite, or nickel and graphite (according to whether the plate is a positive or a negative), covered with perforated steel retaining lids. The positive plates are all connected together within the cell and fastened to the positive terminal, which is brought out through a rubber bushing in the cell cover. A nut, held from unscrewing by a cotter key, clamps the connecting wire to the terminal, outside the cell. The negative terminal is brought through the outer side of the cover in the same manner, and connected outside to the positive one of the adjoining cell.

"There are two other openings in the cover of the cell—one for filling it, and one for allowing gas to escape. The former has a hinged spring cap that opens upon releasing the catch. The gas valve has a mushroom-shaped top that, should the cell be overturned, closes the two small gas passages in the gauze-fitted cap over it, and effectually prevents any liquid from escaping. The fine wire gauze, operating on the principle of the Davy miner's lamp, keeps the gas from firing back and blowing up the cell, should any of that which escapes become ignited. The cell cover fits sufficiently close upon the top of the jar to make a fluid and gas-tight joint.

"Cells of 200 watt-hours capacity are capable of furnishing 160 ampere-hours at an average discharge voltage of 1.3 per cell. They can be run down to 0 without damage, but ordinarily are not discharged below 0.75 volt per cell. Each cell has 24 plates 9⅜ by 4¾ in. in size and 0.1 in. thick. These plates are capable of discharging at as high a discharge rate as 200 amperes without damage. A sample plate was taken from one cell of a set that had run a vehicle 3100 miles over bad roads; the only thing that distinguished it from a new plate was a slightly yellow colouration of the nickel-plated grid and briquette-retaining covers. The briquettes of active material appeared to be in very good condition, thus showing the cell to have a very long life and to be durable. More tests of the new battery are being made on delivery waggons in New York, after which, we understand, it will be placed upon the market this coming spring. One thing is certain, viz. that in the mechanical make-up of his cell, Mr. Edison has made so many improvements over the usual hard rubber jar as to produce a battery very much cleaner, neater, and safer than any that has yet been made. Even in the simple operation of refilling the cell by the addition of water, to replace any that should evaporate from the electrolyte owing to overcharging, provision has been made that the jar should not be filled too full by devising a funnel with a tell-tale float that indicates when the liquid has reached the proper level."

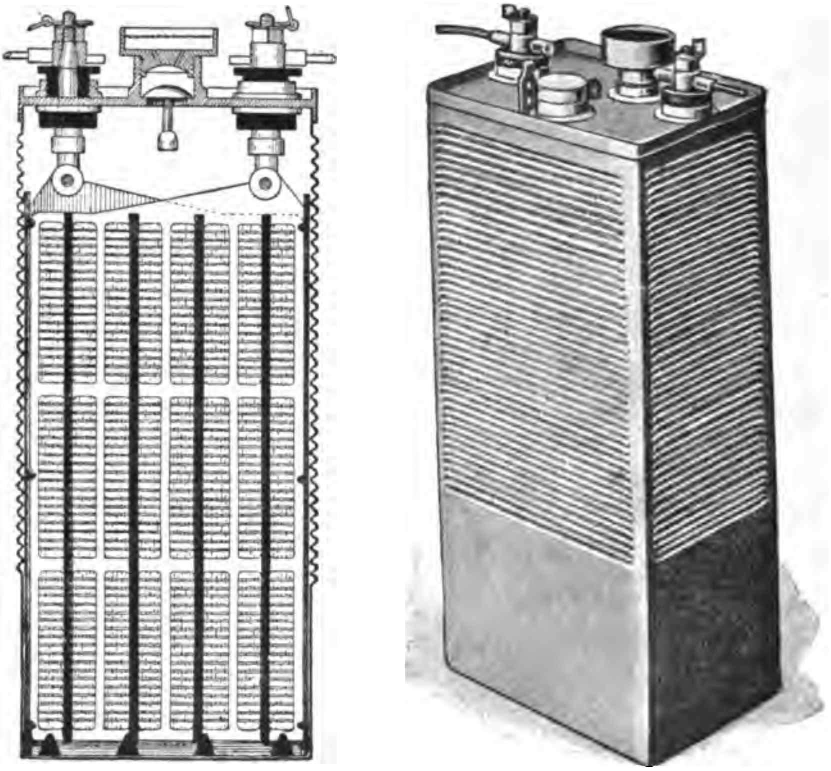


FIG. 152.—Edison's Accumulator

Fig. 152 represents the cells as now made, weighing 18 lbs. for 200 watt-hours capacity, 160 amperes at an average voltage of 1.3.

This gives $\frac{200}{18} = 11$ watt-hours per lb., which is a figure reached by many lead cells, so that on the score of weight there is not much improvement to show.

But weight is of not much importance if we get a cell which will stand the rough work of traction, and this is exactly what Edison's cell offers. The substitution of iron, steel, and nickel for lead is at once a promise of strength and durability.

Another account of this cell in the *Electrical Review*, of London, by Mr. W. Hibbert:—

"The striking feature is the very high percentage of the ampere-hour discharge at the higher discharge rates. The cell is normally rated at 25 amperes, and then gives about 160 ampere-hours at a potential difference over 1 volt. When the discharge current is raised to eight times this normal value, the ampere-hours, with a continuous discharge down to 1 volt, are practically 125. Even then some of the missing quantity is to be obtained at a lower voltage.

"The significance of this is best shown by plotting similar curves for lead cells. They show that at 11 amperes, the ampere-hours are 300, while at 60 amperes (5.5 times as rapid) they are 125. Although recent forms of cells differ in respect of their capacity at different rates, examination would show that no maker of cells would offer a cell giving 75 per cent. of its normal capacity (and practically 90 per cent. at lower voltage) at eight times its normal rate. In a well-known list, the ampere-hour figures for 7 hours' and 2 hours' discharge respectively are as 200 to 120. 'It appears, therefore, that the cell has a great advantage in this respect. During discharge, the density of its liquid is not diminishing, but rather increasing. Hence the ability to call on a greater fraction of the available energy at a higher discharge rate.

"If it be legitimate to calculate the internal resistance from the difference in terminal pressure for various currents, it comes out as varying from 0.001 to 0.002 ohm."

The only other electrical road vehicle possible is that in which the electricity is generated by a combined oil-engine and dynamo working motors on the car axles. This is not such a foolish proposal as it looks at first sight. The engine and dynamo would not weigh half the amount that a cell of similar output or rate of discharge, neither would it occupy so much space, and the generator has its capacity limited only by the quantity of oil carried. The engine can be put down in any place under the car, carried in an underslung box if necessary. The car would have all the great advantages of easy control and perfect command by its driver, offered by electricity alone as a transmitter, and all the ricketty clattering gear required by oil-engines transmitting their power mechanically would be abolished from the car.

Electric Road Car

The Johnson-Lundell Electric Motor Car for road traction is shown in Fig. 153, in which the two motors are shown carried on the back axle with spur-wheel gearing. It is specially designed for storage battery working, and a special controller is the main feature of the system, designed to work on the regenerative principle, so that the motors work as generators and brakes when going downhill or slowing up on a level.

Many attempts have been made to return current to the mains or batteries, most of which have proved abortive, because effective only within a very limited speed range, and because of excessive sparking at the brushes.

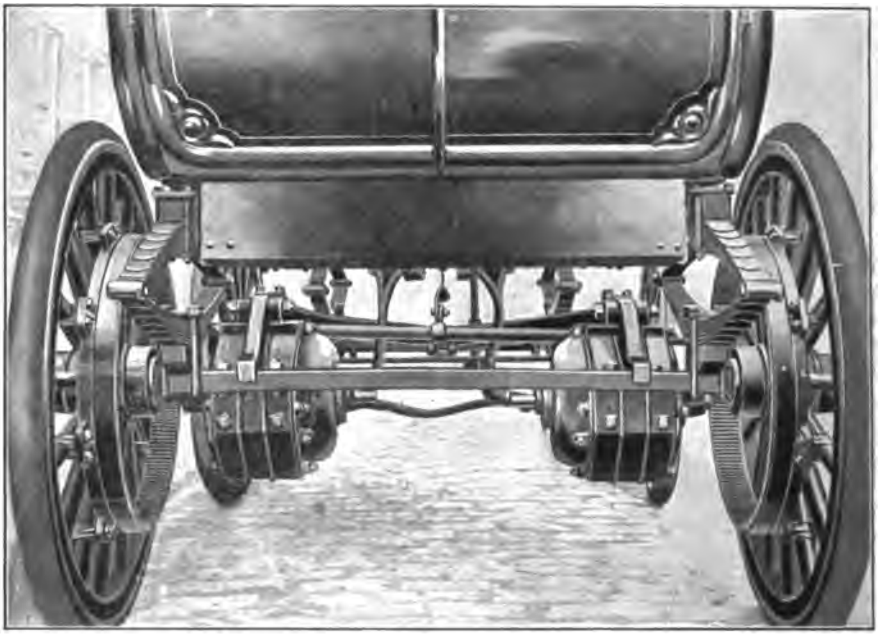


FIG. 153.—Johnson-Lundell Electric Motor Car

The present invention makes it possible to do away with all external resistance, which will cause fall of potential at the armature terminals, and to effectively return current to the line at all but the lowest speed, by reason of the following novel construction of the motor and arrangement of its electric circuits.

Briefly expressed, the invention consists of an electric motor furnished with two armature windings, two commutators, and a field magnet, so constructed that it will be possible to run with weak field strength without sparking at the brushes, and with its electric circuits so arranged that before a current change from series to parallel is made the speed of the motor is so increased by reason of the weakened field, that it will approximate the speed obtained with strong field after the change to parallel is effected. For a clear understanding of the invention reference is made to the accompanying drawings (Fig. 154), in which Fig. 1 is a diagrammatic view of the circuit connections between the stationary contacts of a controller, a motor having two armature windings and two commutators, with a compound wound field magnet, a storage battery arranged in two distinct groups, and the resistances which are used in connection with the field circuits of the motor. Fig. 2 illustrates the developed contacts upon the controller cylinder, the construction of which is similar to well-known form of controller cylinders. Fig. 3 illustrates the developed contacts upon a reversing cylinder of well-known form, which serves to reverse the current through the field windings of the motor.

Fig. 4 is a diagrammatic view of the various combinations of the motor circuits when the controller cylinder, with its contacts, shown in Fig. 2, is rotated over the stationary right-hand contacts, shown in Fig. 1. The motor in this case is supposed to be used in connection with a divided storage battery, as indicated in Fig. 2, for the propulsion of electric vehicles, or for similar uses.

Referring to Figs. 1 and 4, C^1 and C^2 represent the commutators for the two armature windings of the motor. O represents the shunt field winding, and T the series field windings. R, R^1, R^2, and R^3 are resistances, the first two named being in series with the shunt field windings, or short circuited, as the case may be, and the two latter being connected in series to the terminals of the series field winding and partly short circuited, or disconnected, according to the position of the controller. The shunt field is connected across one group of the batteries only for all positions of the controller, as shown in Fig. 1.

It is of course apparent that in the employment of the motor as a generator, the driving power of the moving vehicle being limited, is either partially or wholly absorbed, and the vehicle in consequence checked or entirely stopped, as may be desired. The motor is thus given a third function, viz. that of a brake. Moreover, since the restraining effort of such a brake is always the exact equivalent of the power applied to it, it follows that in it we have an ideal power brake, and that without cost or special mechanical devices. An ordinary hand brake must, however, still be provided to hold the vehicle at rest on a grade, in consequence of the non-functional character of the motor brake when not in motion. This hand brake may nevertheless be considered rather as an emergency device than otherwise, as the motor brake will be available for all ordinary requirements.

An important incidental advantage attending the use of the motor, both as a motor and as a brake, is, that as the driver is required to manipulate but one lever, less alertness is exacted of him.

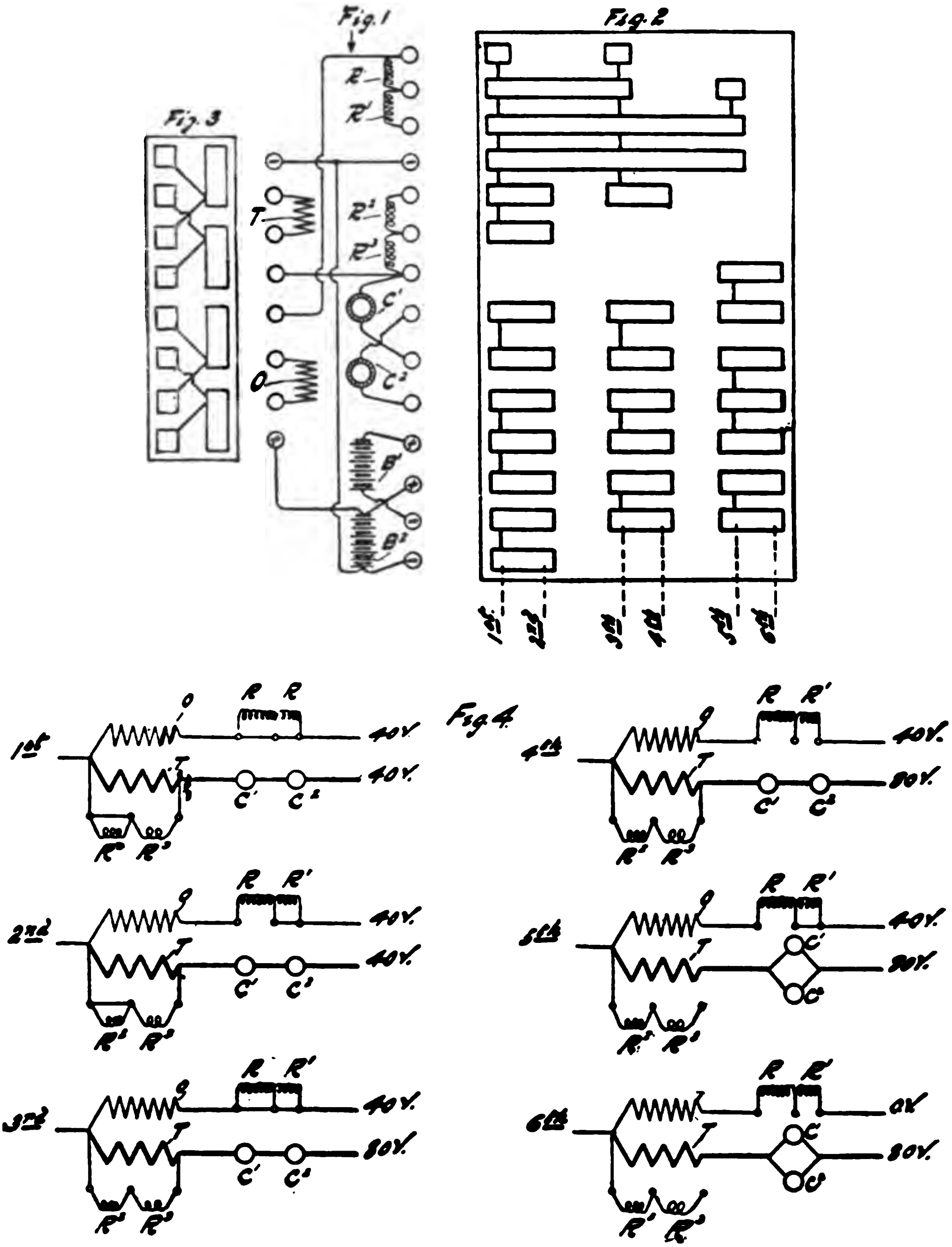


FIG. 154.—Controller Circuits

Another important item is in the saving of the wear and tear incidental to mechanical brakes.

An excessive current will not cause sparking at the brushes, for the reason that at the first and second position of the controller the difference of potential between consecutive commutator bars is only one quarter of that at top speed. Second, should the speed of the vehicle materially exceed the speed corresponding to a certain position of the controller No. 1, No. 2, or No. 3, by reason of running down-hill, it follows that the motor will automatically become a dynamo, and will thus restore energy to the battery. Third, should the vehicle happen to be running at top speed, and the controller be quickly returned to positions No. 2 or No. 1, it follows that a rather excessive current will flow through the armature windings, charging the battery, but at the same time will be kept within safe limits, on account of the weakening effect of the series field, which, by reason of weakening of the field strength, will correspondingly reduce the electro-motive force of the armature. The charging of the battery is in a measure regulated automatically; viz. a heavy charging current will weaken the field and thus reduce the electro-motive force, and a small charging current will strengthen the field, and thus increase the electro-motive force.

If batteries ever become perfect enough for traction there is no doubt some such system of motor control must be employed, but it requires for its complete success some means of indicating the balance of charge and discharge, without which it would be impossible to know how the system comes out in actual work done by the cells. For this purpose the Thomson-Houston watt-hour meter, as used on tramcars, might be modified for use in this necessary balancing of output and input.

The full-page Plate VII. illustrates an electric traction locomotive for haulage on short lines, as constructed by Messrs. Fowler & Co. of Leeds.

Electrical transmission of power to canal boats has often been proposed by people who were evidently entirely ignorant both of canal economies and electrical transmission of power. It requires no demonstration to prove that a trolley system with a motor and propeller on the boat would work satisfactorily, but the cost per ton mile hauled would be at least ten times greater than the present cost of haulage by horse. Some enthusiasts seem to assume that because a thing is done by electricity that it is necessarily done better than by other means. That, however, is a great mistake, so long as electricity is only a transmitter of the power of prime movers, and it is only that and nothing more at present; its applications are limited. The canal boat electrically propelled is outside the limit, so is the ocean ship for the same reason.

The only possible application of electrical energy is one of transmission of power within the ship itself. It might be under some circumstances useful to drive an electric generator like a steam turbine and dynamo of small dimensions compared with its power, and at high speed, 10,000 or more, and from this to run the propeller or propellers by slow-speed motors. Such a system would present considerable advantages in warships of smaller sizes; the propeller could be controlled by a controller by the officer on the bridge, as easily as a tramcar driver controls a car. In the same way oil-engines or gas-engines could be employed on ships.

The propulsion of pleasure boats on rivers, lakes, and at seaside resorts by electricity carried in storage batteries has been to some extent successful, and from all accounts of Edison's Alkaline Iron Nickel Battery this application is likely to be further extended, as, other things being equal, an alkaline cell is preferable to an acid cell in any case. The steel cases of the cells are light and unbreakable, and that is an advantage attending the use of alkaline electrolyte in traction work.

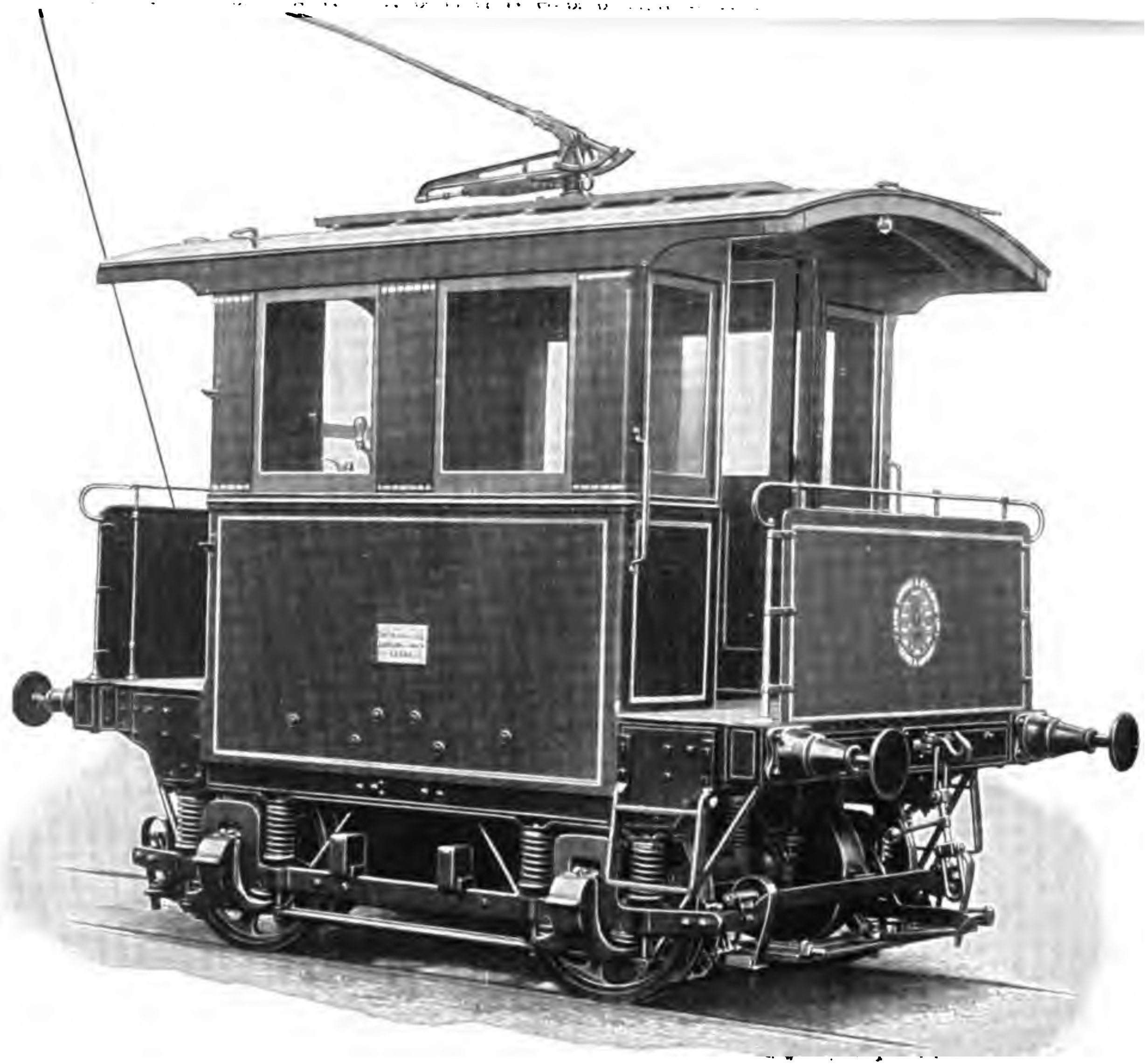
It has been already pointed out that one great help in maintaining storage cells in first-class order is an instrument in the circuit which records in watt-hours or ampere-hours the input at charge, and the output of discharge between the charges. More cells are ruined, and electric propulsion discredited through the want of knowledge of Dr. and Cr. state of the cells; if they are a few times subjected to an overdraft, failure soon ensues, and again waste goes on often by long charging which may at the time not be required. We want some means of knowing just what we put in and take out, and what balance is on the right side of the account. The author has had an instrument of this kind on trial on traction cells, which promises to be a practical check on this balancing of the charges and discharges. Fig. 155 represents a launch fitted with cells for propulsion by motor and screw.

Electric launches have been much improved within the last year or two, and owing to the more efficient accumulators now obtainable the length of run is much greater than it used to be.

On the Thames there are now a number of charging stations where launches can be charged at moderate prices.

The smaller boats have a speed of 5 miles per hour for 5 hours, increasing in the larger sizes to 7 and 8 miles per hour for 6 hours, or at the slower rate of 5 to 6 miles per hour for 20 hours.

These launches will be found a great convenience wherever facilities exist for re-charging the accumulators. Where electric lighting is used the same dynamo can be employed for this purpose. The whole of the electric and reversing arrangement have been rendered so simple that they are controlled by one handle, and no engineer is required. As the more important steam vessels and men-of-war are now equipped with all necessary electric lighting



LIGHT RAILWAY ELECTRIC LOCOMOTIVE

appliances, it is evident that their boats might be advantageously and without difficulty fitted with accumulators and motors. Their superiority over rowing boats for port and other purposes is unquestionable, and the accumulators may serve while the launch is on its davits to regulate the E.M.F. of the ship's circuit during lighting.

A 20-foot electric launch in teak or mahogany, fitted with motor, accumulators complete, ready for working, length of run with one charge, 5 miles an hour for 5 hours, costs about £200.

The illustration is kindly lent by the G.E. Co. of Manchester.

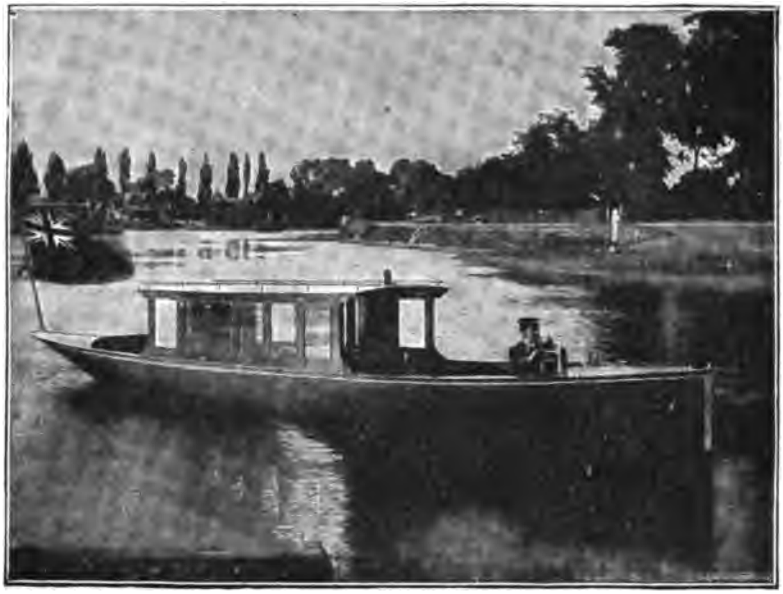


FIG. 155.—Electric Launch

We will now pass on to the consideration of ship lighting plants.

One of the very first applications of electric light was on board ship, where its great convenience and cleanliness was at once appreciated.

Steam is plentiful, and the marine engineers, who as a rule are an intelligent and handy class of engineers, took kindly to the innovation from the first.

Ship Lighting Installations.—Here again we have a case where the installation and all its elements must be of the simplest and least troublesome possible. Larger ships can afford to carry one engineer with a special knowledge of ship electric plants, but smaller ships rely more upon the simplicity of the plant, and its good performance under the ordinary marine engineer's care.

Small direct coupled engines and dynamos we have already shown in Vol. III. for ship lighting. Larger plants generally consist of compound or triple expansion direct coupled engines and dynamos, but the best plant for a steamship is beyond doubt a steam turbine plant, and many have been adopted; and a still further improvement upon the older types of ship lighting plants has been effected by using an alternating generator single-phase or three-phase, and self-exciting much on the lines of that shown at end of Vol. III. for small sizes. For larger sizes the inductor type of machine, with no brushes, no commutator, and no moving coils in the generator are preferable. The high speed of the turbine is a positive advantage in alternators, as we thereby obtain a moderate frequency with few poles, thus reducing magnetic leakage, which is always a great drawback in alternators. A frequency of 50 at most is desirable. A pressure of 80 to 100 volts is quite high enough for anything on board ship, and good heavy wiring desirable, while the lamps are more durable at this lower pressure, the insulation safe, danger a minimum, but danger from shock is not entirely eliminated at any pressure practicable.

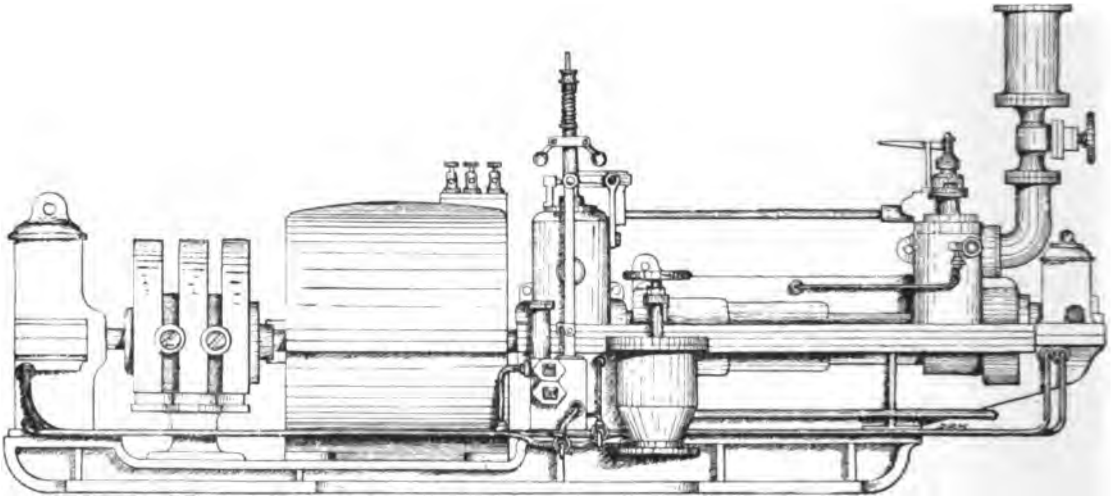


FIG. 156.—Steam Turbo Alternator

Fig. 156 is a design for an alternator and steam turbine combined for ship lighting. Absolutely without a brush or a commutator, the rotating field magnet is excited from the rotating armature of the magnet to exciter. The regulating of the pressure to a constant P.D. is effected by a booster. The armature of the generator is fixed and formed of laminated stampings, slotted and wound much the same as the stator of an induction motor, Fig. 157. Larger generators may be made on the inductor type with one coil exciting several pairs of poles, or on the Kingdon type of inductor dynamo, a machine which at one time promised great things, but owing to the death of the inventor, and the liquidation of the firm who held the patents, has dropped out of competition with others. It has some electro-magnetic leakage, but not excessive; it is a simple machine to make and repair, with well-made small exciter; it is an ideally simple generator; it is therefore here briefly described and illustrated for those interested in ship lighting. Fig. 158 is an end view. The armature and field coils are both carried upon an outer ring with inward projecting limbs; the poles with the fine wire spirals are the field magnet poles; the intermediate limbs with thick wire are the armatures with generating coils; the inductors A.A.A. are carried between two non-magnetic discs on the shaft, and consist of segments of laminated iron. As the inductors rotate in front of the poles, the magnetic flux is alternately reversed in the thick wire coils, thus setting up an alternating E.M.F. without any moving coils whatever, except those of the exciter, which is only a small series dynamo.

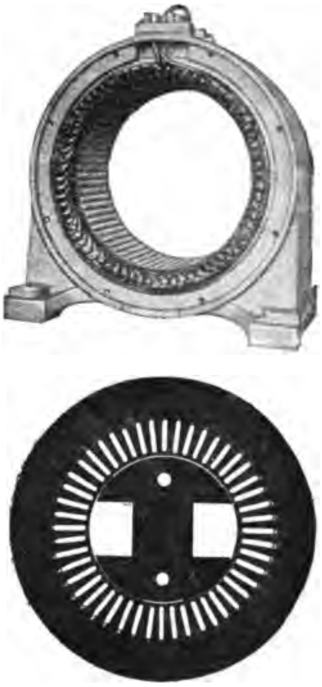


Fig. 157.—Ship Lighting Dynamo.

Fig. 159 is a cross section showing the laminated field and inductors.

If the wiring of land premises is somewhat diversified and peculiar, the wiring of ships is more so. Some contractors simply adhere to the simple two wire, in wood casing throughout, run up by carpenters and joiners, who also lay in the wires with loops left out for the "electrician" who follows to put up the distribution boards and fittings. This system is simple, and is well suited to the class of contractor who buys the whole outfit ready-made, and only undertakes the fitting in of the installation; if the insulation on the wires is good and thoroughly waterproof, and the casing only acts as a mechanical protection, it is good enough, and many ships are so fitted.

A single wire or concentric wire system with the outer covering as an earthed return is far better. This system with cast-iron distribution boxes makes a good engineering job. One of these boxes is shown in Fig. 160, by Messrs. Dorman & Smith, with sliding porcelain switches and damper displacement fuses; the lid is hinged and rubber jointed. These main switch-boards are placed at a few convenient places on the ship, and from these the single-light fuse boards are fed.

Ship Lighting

Fig. 161 shows ship fitting for bulkhead and deck lights, same enclosed so that it may be shut up water tight by a hinged lid to protect it.

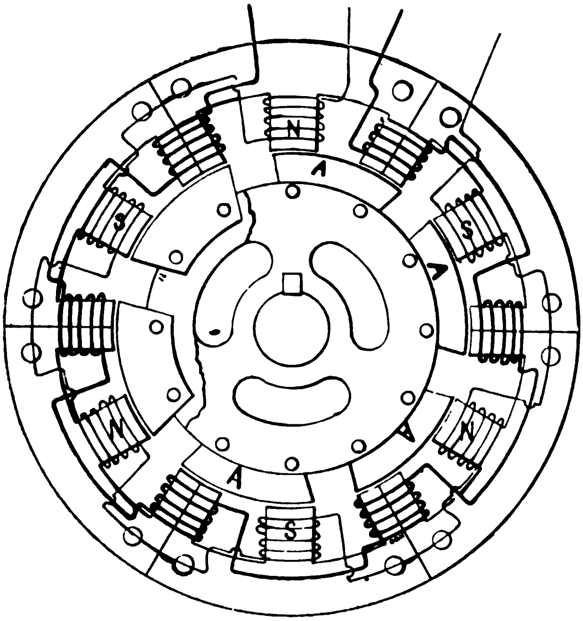


FIG. 158

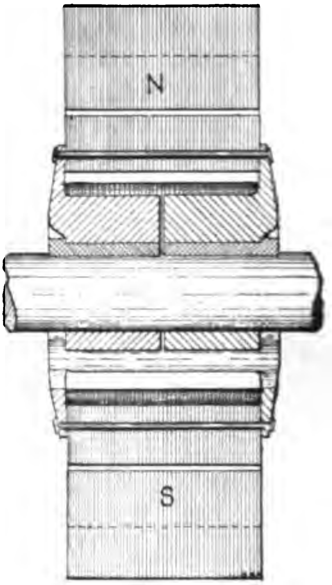


FIG. 159

Kingdon Alternator

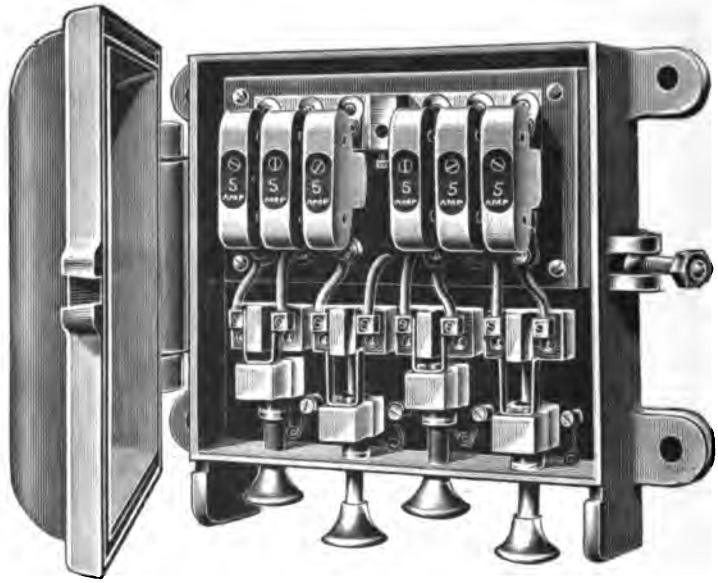


FIG. 160.—Distribution Box

Fig. 162 shows a short-arm protected side light in water-tight

Ship Lighting Fittings

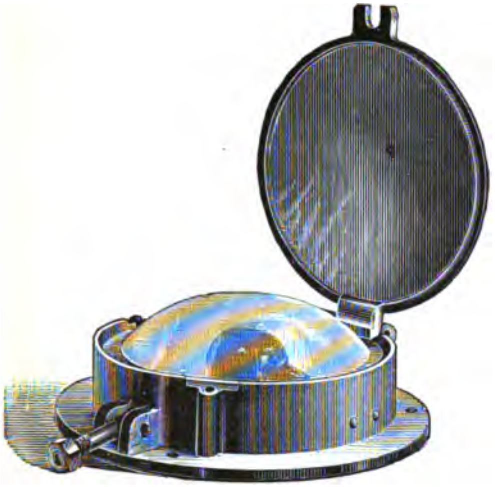


Fig. 161

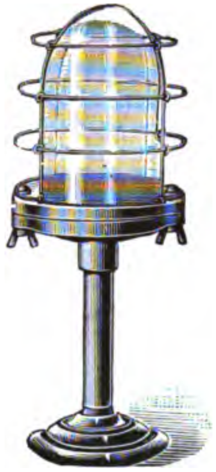


Fig. 164

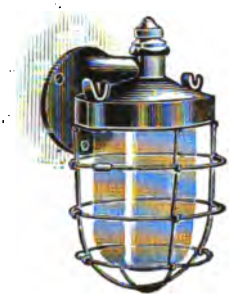


Fig. 162

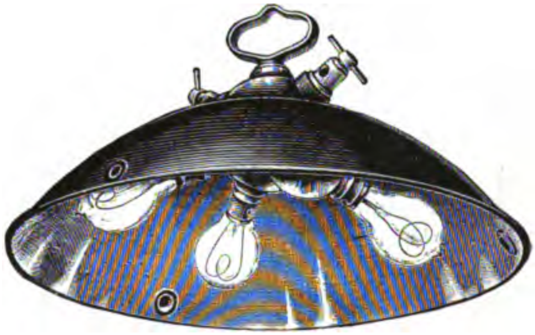


Fig. 165

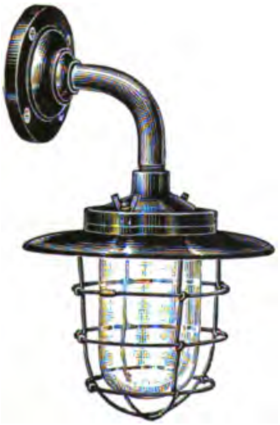


Fig. 163

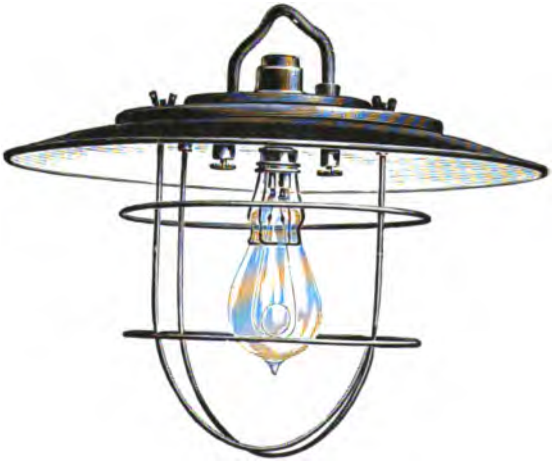


Fig. 166

Fittings for Ship Lighting

globe and cover, and Fig. 163 shows another bracket form, while Fig. 164 shows a pendant. These are iron fittings for the more exposed and working parts of the ship.

For lighting up the hatches and decks and gangways at night when discharging cargo, a large group of lamps in a large reflector is very useful (Fig. 165). When connected by a plug connector by a twin flexible wire, it can be slung up where most convenient.

Fig. 166 represents another, with only one large lamp of 200 to 500 candle-power.

The side signal lamps should have two lamps wired to a change-over switch, like the little switches shown in Vol. II., page 190. In the event of a lamp failing, the other may be at once switched on; the same for the masthead light is also advisable.

Nowadays most important shipbuilders employ their own wiremen and electric light fitters, and follow the practice of the Admiralty, who fixed upon 80 volts as a working electric pressure, because it suited the search-lights so well. These search-lights are simply large arcs in the focus of a large parabolic reflector, so that it can be moved out or in from the reflector in order to produce a convergent, a parallel, or divergent beam of light. In operating a search-light, the operator actually sees a convergent beam when it is parallel, and a parallel beam when it is divergent; this is due to the perspective vision of the eyesight. In a perfectly clear atmosphere the beam of light would be invisible; its visibility in our atmosphere is due to the light striking dust, smoke, and water particles suspended in the air.

The application of electricity to motors on board ship has not met with the reception to be expected of it. The adoption of electro-motors to winches, hoists, pumps, fans, and even to steering gear would prove a great advantage. The leading of steam by pipes to the engines now employed for these purposes is a practice which should be abandoned; good motors and simple wiring would do the work far more effectively and with much less trouble. The three-phase motor would be preferable for these purposes

CHAPTER VI

SPECIAL APPLICATIONS OF ELECTRO-MOTORS

THE transmission of power to travelling cranes was always a mechanical difficulty, square shafts and ropes being used, and some even using an engine and boiler carried on the crane. The electric system was at once recognised as a great improvement, and older existing cranes driven by square shaft and ropes were in many cases converted by fixing a single motor on the crane with a trolley wire and pulley to operate it. Generally the motor was geared by worm gearing to the first shaft of the crane. Such conversions from mechanical to electrical transmission has in every case shown a great improvement.

In constructing electric cranes it is common now to use three motors, one for each movement, and in Fig. 167 the three motors are seen on a large overhead crane. The top motor is for lifting and lowering, the middle motor is for transverse moving, and the lower one for running up or down the shop. This is the best system, and is generally adopted. This crane has continuous current motors series wound, and they can be easily started by a controller under full load, constructed much as a tramway controller, shown in Fig. 131.

Another arrangement using polyphase motors is shown in Fig. 168, showing the three motors and their gearing. The continuous current crane is, however, more perfectly under control.

In some cranes brakes are automatically operated when lowering.

Messrs. Crompton & Co. have a wide experience in cranes. A most useful and much used type of warehouse crane is shown in Fig. 169, with two motors, one for swinging the jib, the other for lowering and raising the jib and hauling the chain. It is perfectly self-contained, and besides its use in warehouses it is a type of crane useful in handling forgings around steam-hammers, presses, and furnaces, where the traveller crane is not applicable.

It is also a type of crane for building operations, a substitute for the steam crane with the boiler attached. Several of these cranes can be operated simultaneously from one engine and dynamo on the ground level with advantages; for much time is lost in lifting by one crane only, where several could be used.

A very well designed hoist is shown in Fig. 170, with automatic starter. The rope pulley for starting switches on the current by operating a rack which works the switch and the brake. As the

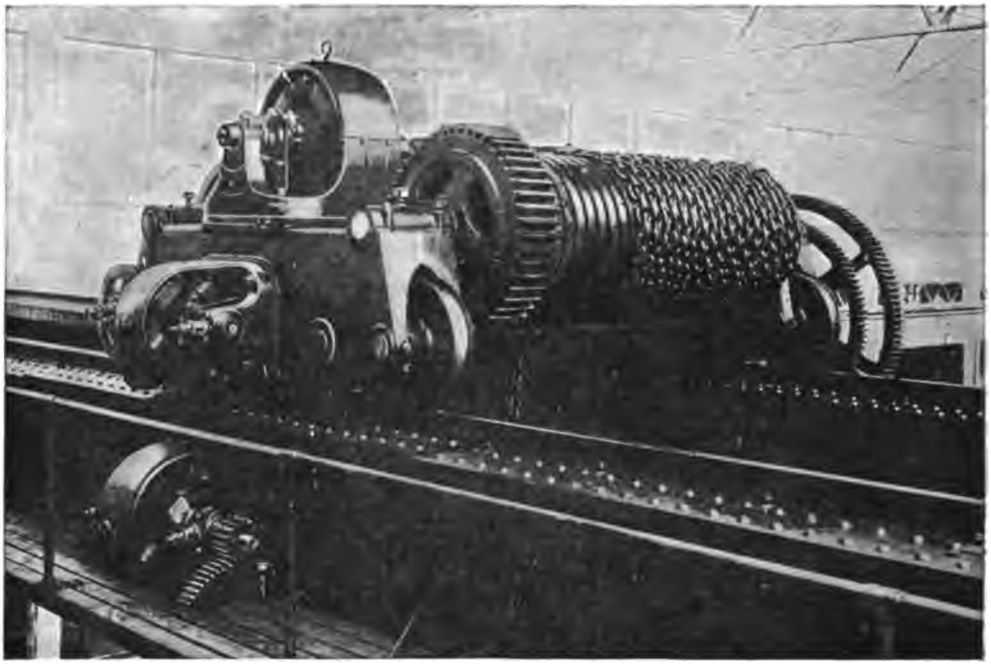


Fig. 167.—Crane worked by Three C. C. Motors

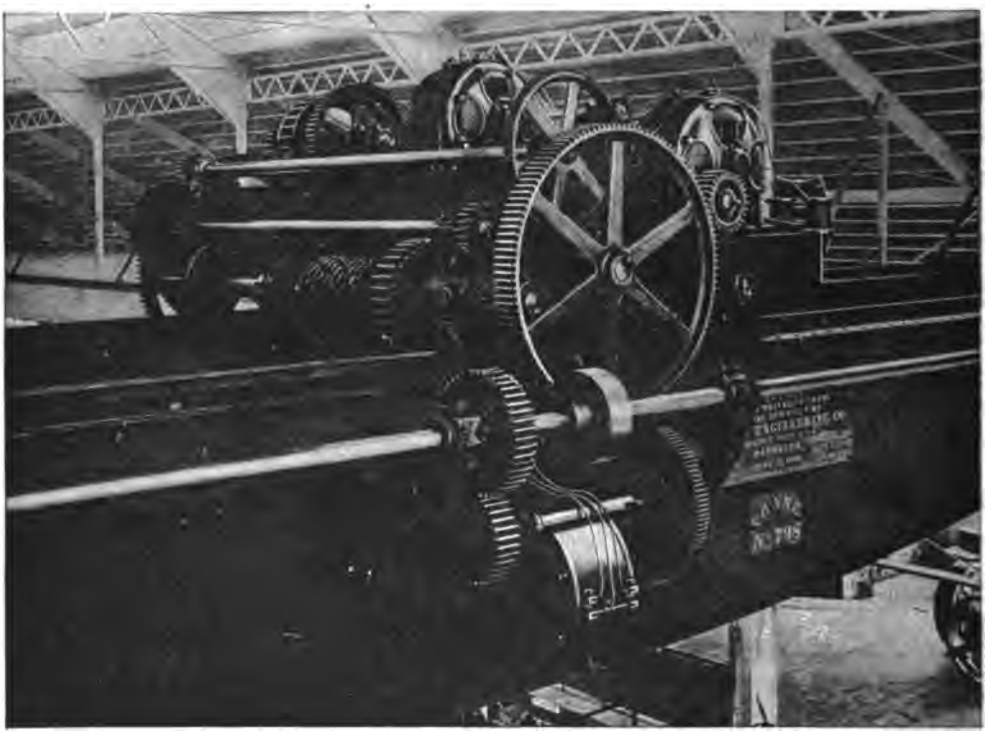


Fig. 168.—Crane worked by Three Polyphase Motors

motor moves it winds up the starting resistances by the small rope pulley driven from the motor shaft, thus providing a gradual start and stop, avoiding the disagreeable jerks common with some hoists.

The Western Electric Company's hoist is shown in Fig. 171. The machine is operated electrically by either a button or a small lever, which, when released either accidentally or otherwise, will stop the machine. The controller so actuated admits current to the armature only to the extent of its capacity. The armature then, by its own motion, so controls the current, that the maximum speed is reached by equally graduated steps, and without any shocks or sudden fluctuations of the current. Any overload will automatically reduce the speed by increasing the strength of the field of the motor, with a consequent reduction of current taken by the machine. At the terminal landings the machine is automatically slowed down electrically and brought to rest by a brake which is independent of the control of the operator, should he fail in his duty. Moreover, should the car have an excessive load, this final and automatic stop at the terminal landings will be made absolutely certain through the automatic action of the machine itself, by means of an extra terminal brake specially supplied for this purpose. Other safety devices are also applied to the cage and the car in the usual manner to prevent excessive speed when the current is cut off with a descending load, and to lock the car to the strips should the cables be cut or broken.

An additional safety device is provided to stop the car if any obstruction meets it in its descent, or should any foreign body be wound between the cables and its drum, no matter in what direction the car may be moving.

I have purposely selected these examples as showing complete electric hoists, self-contained, with simple but effective starting switches and resistances and controlling apparatus, in contradistinction to the motor coupled to a worm gear which some makers are pleased to call an electric hoist. As a matter of fact, the controllers, the brakes, and gearing are of more importance than the motor in any hoist, and contracting electrical engineers should examine these vital points with the keenest scrutiny in selecting an electric hoist.

The electric conveyer can be employed in many places where ordinary lifts are useless. The overhead runner is a very useful and convenient system, provided the rails can be safely suspended from the roof. A conveyer has been for many years at work in Victoria Station, Manchester, for carrying passengers' luggage from platform to platform.

It can be most conveniently applied where there are no over-

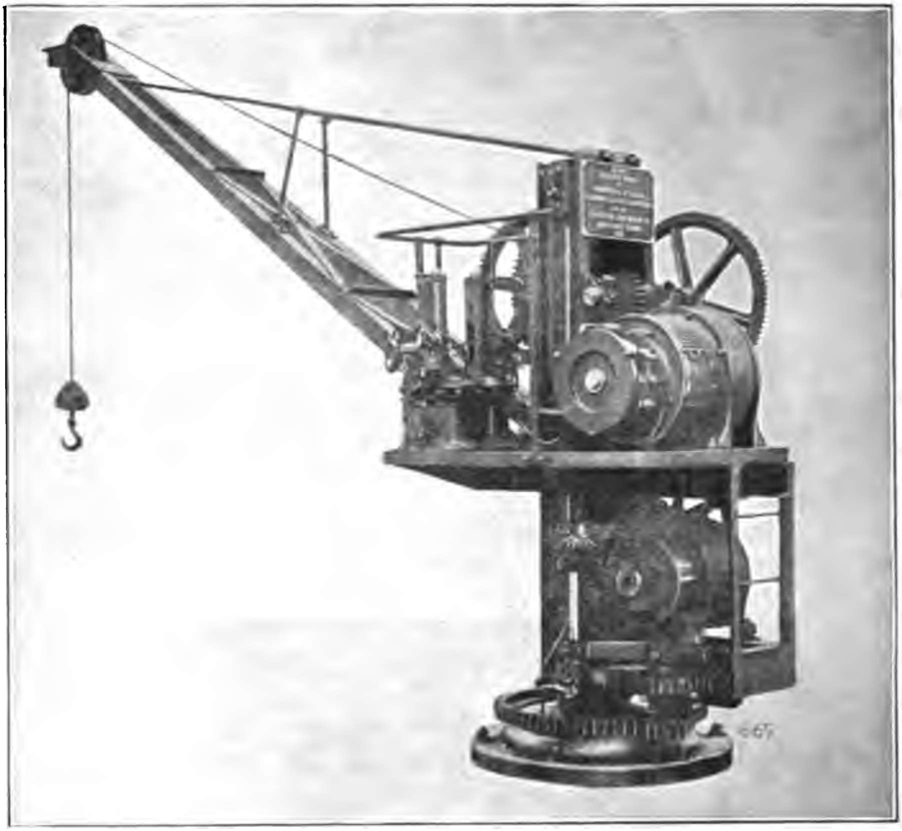


FIG. 169.—Electric Jib Crane

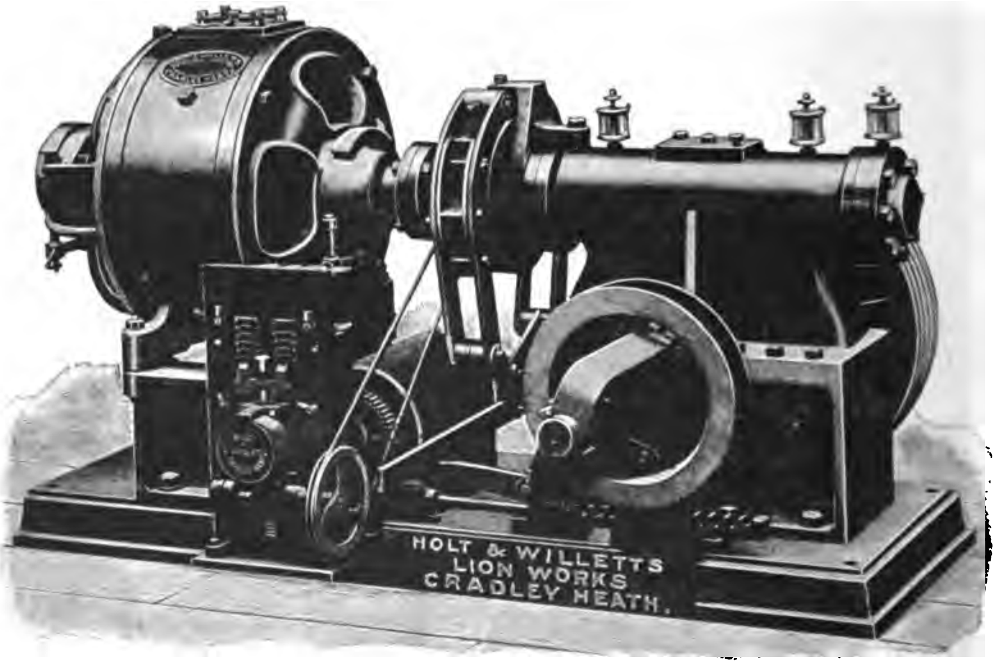


FIG. 170.—Complete Electric Hoist Gear

head obstructions, and will be found invaluable in many factories and works, as it will take short radius curves and go into corners inaccessible to any system of floor tramways. It can travel through windows from one building to another, as shown in Fig. 172.

The electric conveyer has no complicated mechanism rendering it liable to get out of order, or necessitating constant adjustment, nor are there any special electrical attachments which require a skilled attendant. The apparatus is a simple electric locomotive and crane combined, with a framework and motor mounted in such a manner that it also carries the seat occupied by the man in charge, who has the regulating handles within easy reach and under his control.

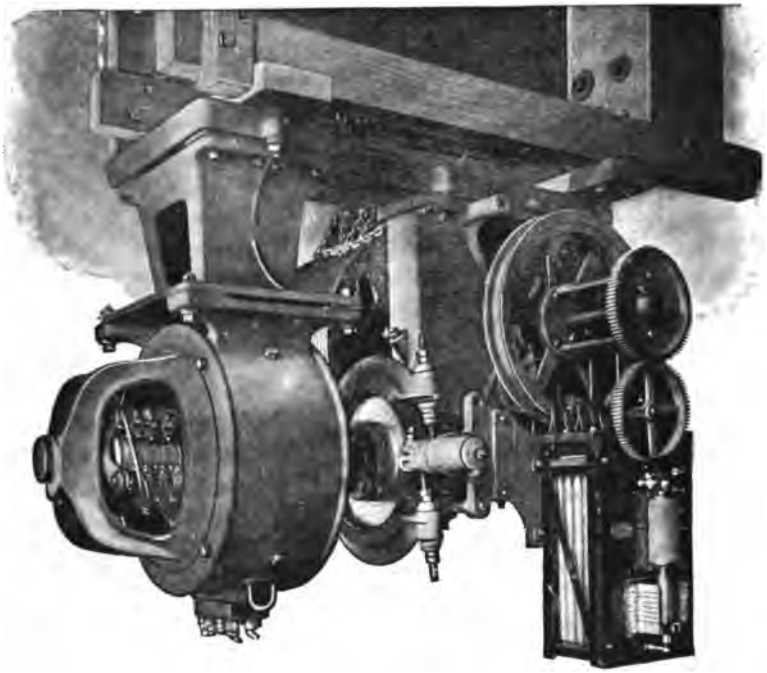


FIG. 171.—Complete Electric Hoist Gear

The electrical portion of the conveyer has been designed upon special lines, and care has been taken to eliminate complicated electrical accessories. The motor, which is one of Mather and Platt's well-known steel-clad type, is mounted underneath the framework, and drives a vertical shaft. On this shaft a clutch, working in ball-bearings and provided with two friction cones, can be moved up and down by means of a lever fitted with screw adjustment, the hand wheel of which is within easy reach of the operator; when the clutch is at the lowest point of its travel, the upper cone is out of gear, while the lower cone is in gear with a worm on a sleeve surrounding the vertical shaft, this worm working into a worm-wheel which drives the hoisting drums. When the clutch is at the highest point the lower cone is out of gear, whilst the upper one is in frictional contact with the gear for actuating the driving wheels of the locomotive. The whole of the motions are controlled by one lever actuating the clutch, and one electric switch controlling the current. This switch is of the simplest electrical construction, having none of the defects usually met with; the contacts liable to injury by sparking can be replaced in a few minutes by unskilled labour, thus making the only vital parts of the switch as good as new at the cost of a few pence. The action of the switch is to reverse the direction of rotation of the motor, and this, in connection with the mechanical clutch, enables the operator to lift, lower, or travel in either direction at will.

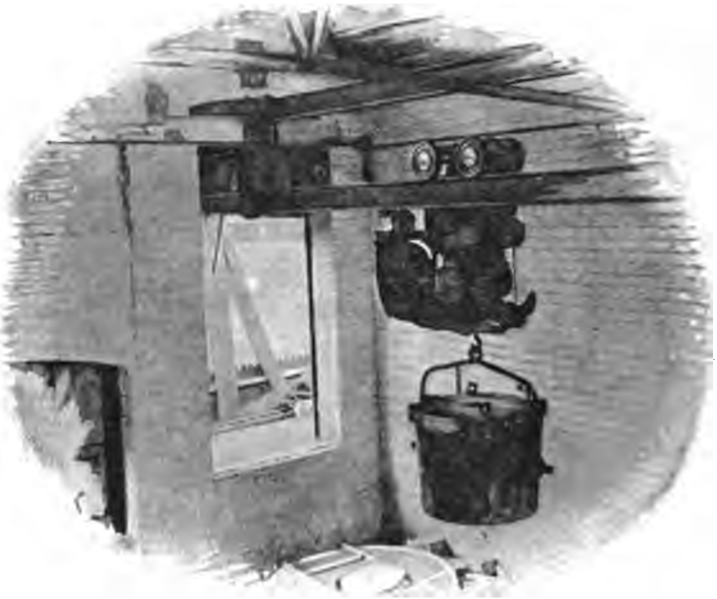


FIG. 172.—Electric Conveyer through Window

The illustration, Fig. 173, shows a conveyer designed to lift 15 cwts. at a speed of 26 feet per minute, and to travel at a speed of about 700 feet per minute (8 miles per hour). The current taken at starting, when lifting this load, is about 40 amperes at a pressure of 100 volts, but this quickly decreases as the hoisting proceeds; the current required for running is considerably less than this.

Electric Conveyer

The electro-motor is particularly suitable for centrifugal fans and pumps, their motion being rotary, and quick, direct coupling as compact as possible is the correct thing. The Thomson-Houston fan, illustrated in Fig. 174, is a good example of a good design. The field magnet is bolted direct upon the side of the fan, with the armature on the fan shaft. We have already shown the high lift pumps of Messrs. Mather & Platt with direct coupled motors. The full-page illustration shows pumps operated by combined electric motors and water turbines in a large installation. All three machines being purely rotary, exceedingly smooth and efficient working is ensured, with silence, and with no internal valves.

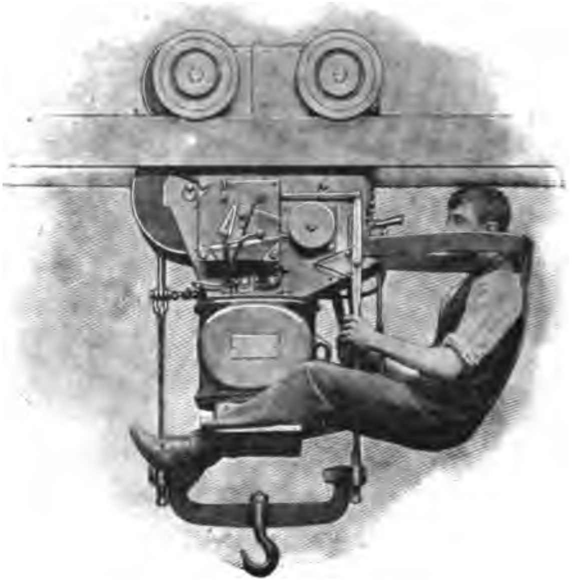


FIG. 173.—Electric Conveyer

Another very useful application of motors is that to portable machinery, wherein the tool is taken to the work, instead of taking the work to the tool. Fig. 175 shows a portable drill operated in this way by a portable motor and controller, all self-contained, with a flexible shaft connecting the motor and drill. This is a B.T.H. motor with three speeds; the end of the flexible shaft can be attached to any of the three shafts shown on the motor case.

For these purposes it is often desirable to have a variable speed motor, which will increase in torque as the speed decreases, and *vice versâ*. By using a very strong field this can be accomplished by regulating resistance in the shunt circuit of the motor.

The flux Z should for this purpose be calculated by my formula, wherein Z is the total magnetic flux in Kapp lines through the armature :—

$$Z = \sqrt{KW} \times 400 \times \sqrt{\frac{1000}{n}}; \text{ or}$$

$$Z = \sqrt{KW} \times 600 \times \sqrt{\frac{1000}{n}}.$$

See page 130, vol. iii., where the constant multiplier is taken at its lowest possible, 200. But 300 is more common for constant speed machines. But for motors to be varied in speed by shunt resistances we must go up from 400 to 600 for this constant. Take, for instance, a portable motor to vary in speed from 1200 down to 400, with increase of torque as the speed goes down, and say it is to give 2 KW.

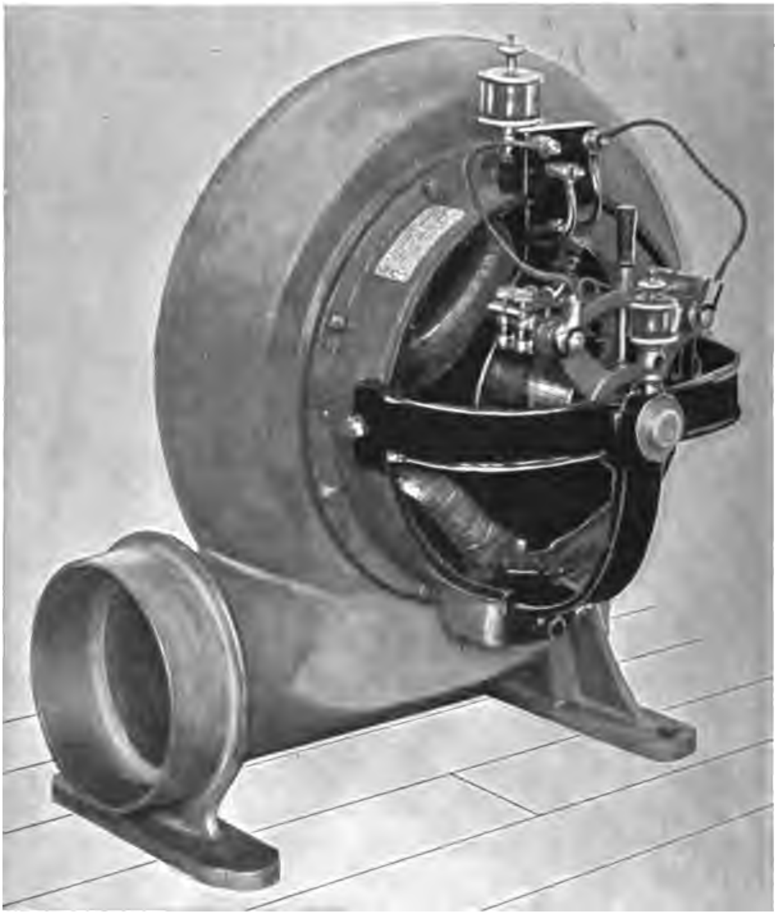


Fig. 174.—Electric Fan

$$\sqrt{2} \times 600 \times \sqrt{\frac{1000}{400}}.$$

Hence $1.41 \times 600 \times 1.6 = 1350$ total magnetic flux. A four-pole machine, with 67.5 of a flux through each pole, would be best, and dividing this 67.5 flux by 15 should give the cross section of the magnet limbs in this motor, $\frac{67.5}{15} = 45$ square inches or $7\frac{1}{2}$ inches diameter. This flux is calculated for the lowest speed, 400, giving 2 B.H.P.

As we reduce the flux by putting in resistances in the shunt the speed rises and the torque falls, thus maintaining the power constant or nearly so; and as the field is still strong compared with the back and cross ampere turns of the armature, sparking does not occur at the highest speed. The current in the armature is the same at all speeds for the same power.

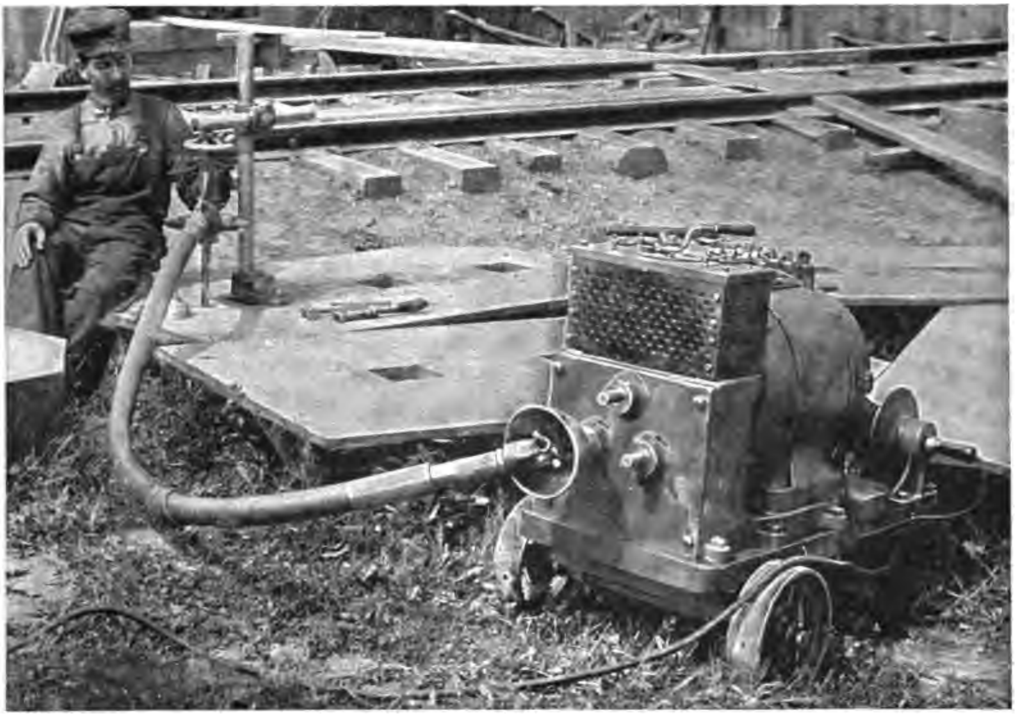


Fig. 175.—Portable Electric Drill

At full speed, 1200, the flux would be approximately one-third of the flux at 400, or $\frac{1356}{3} = 452$.

I have designed motors on these lines for many variable speed applications—for boats, portable drills, grinders, drilling machines, and turning lathes.

Fig. 176 shows a motor geared to a large turning lathe by the Westinghouse Company.

Variable speed is not attainable by alternating single phase or polyphase induction motors, hence most of these applications are made by continuous current motors and controllers.

The application of electro-motors to all purposes, superseding belts and shafting, is going on rapidly, and is at present the chief line of electrical engineering. Electrical transmission of course lends itself best to stationary machinery, and at present this is due to the want of a portable generator any better than a combined oil motor and dynamo.

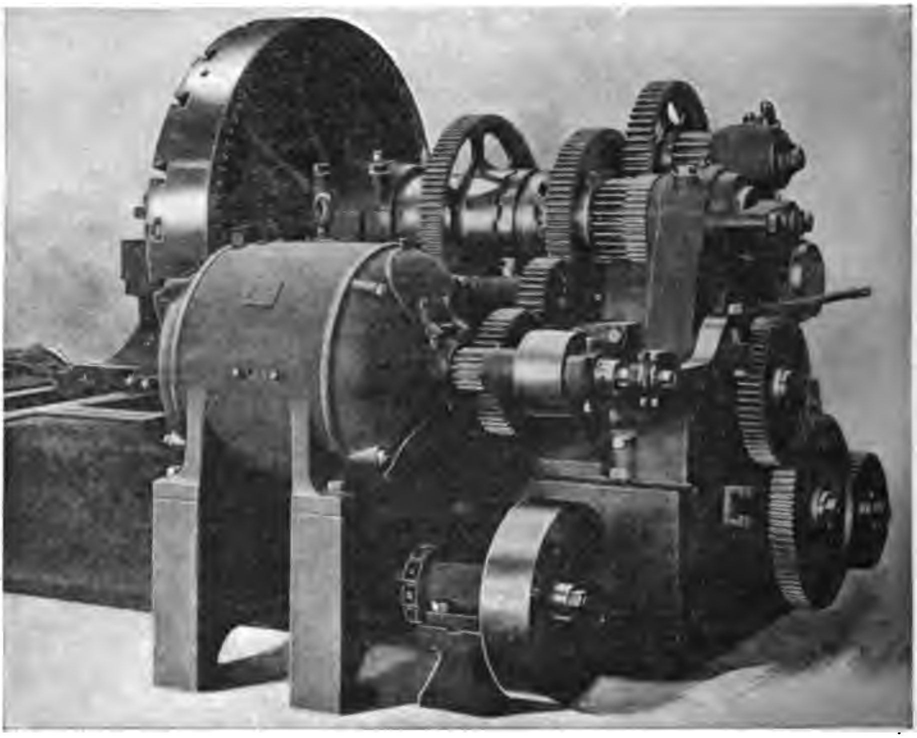


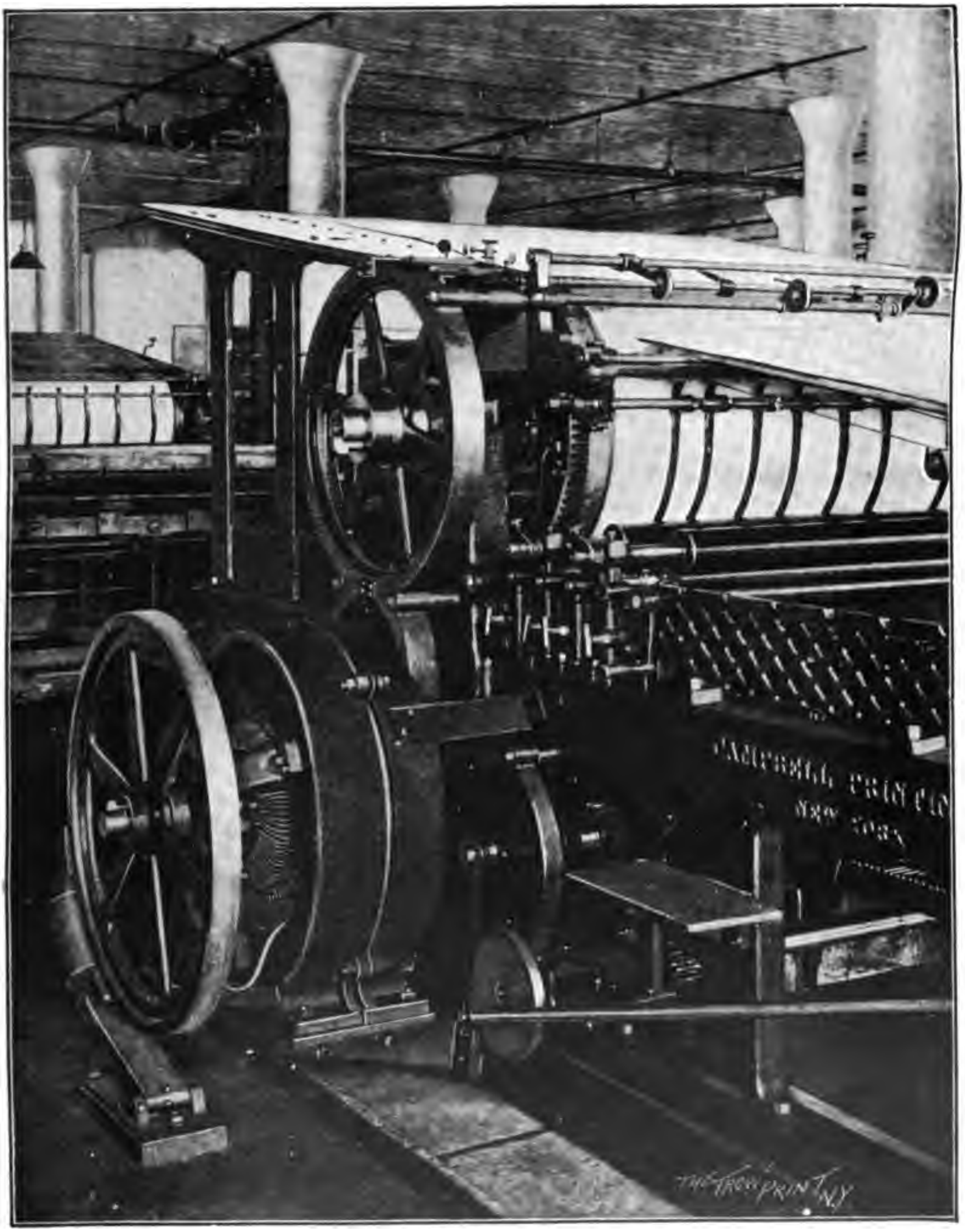
Fig. 176.—Motor-Driven Lathe

In regard to power required for running various tools by motors.

Planing machines.—The power required to plane metals is given by formulæ as under :—

For cast iron.—Let W represent the weight, removed per hour in lbs., then horse-power $= W \times \left(0.016 + \frac{1}{10{,}000 \times \text{the cut}}\right)$. The cut can be calculated easily from its depth multiplied by the feed giving the sectional area of the shaving of metal in square inches.

For soft steel, horse-power $= W \times .12$
For soft wrought iron, horse-power $= W \times .05$
For hard gun metal, horse-power $= W \times .013$



MOTOR-DRIVEN CENTURY TWO-REVOLUTION PRESS WITH MAGNETIC BRAKE ON FLY-WHEEL

Work of Motors

In lathes metal is removed with less power than in planers.

For cast iron, horse-power required = W × .03
For wrought iron, horse-power required = W × .04
For steel, horse-power required = W × .05

In shaping machines for cast iron the H.P. for skin cuts = 0.1 × W.
In shaping machines for cast iron the H.P. for under cuts = 0.07 × W.
In shaping machines for cast iron the H.P. for notch cuts = 0.12 × W.

The following are results of tests in driving wood-working machinery by Professor C. G. Dodge :—

Table C.

Showing Speed and Horse-Power Required to Drive Wood-Working Machinery.

Description of Machinery.	Revolutions Per Minute.	H.P.
Circular saw bench. Size of saw, 14 in. diameter . .	2500	1
” ” ” 24 in. ” . .	1500	2
” ” ” 30 in. ” . .	1150	3
” ” ” 36 in. ” . .	1000	4
” ” ” 42 in ” . .	830	5
” ” ” 48 in. ” . .	700	6
Band saws. Diameter of saw pulleys, 24 in. . . .	500	...
” ” ” 30 in. . . .	450	¾
” ” ” 36 in. . . .	400	1
” ” ” 42 in. . . .	350	1½
Vertical timber frame saw for . . . } 12-in. logs. Speed of crankshaft	180	3
” 18-in. logs. ” ”	160	4
” 24-in. logs. ” ”	140	5
” 34-in. logs. ” ”	130	7
Double deal frame for deals . . } 11 in. by 3 in. ” ”	400	4
” 14 in. by 4 in. ” ”	350	5
” 18 in. by 4 in. ” ”	300	7
Single deal frame for deals . . . } 11 in. by 3 in. ” ”	400	2
” 14 in. by 4 in. ” ”	350	3
General joiner	1500	3
Boring, chamfering, and shaping machine . . .	4000	½

As to the saving in power by electric transmission. The total loss in electric transmission can be summed up as follows :—

Dynamo, including friction	6 per cent.
Wiring	3 ”
Motors (small)	15 ”
Gearing (raw hide)	5 ”
Total . . .	29 per cent.

The loss in mechanical drives varies very much, as may be seen from the list below, as given in an engineering magazine.

Economy of Electric Transmission

TABLE D.

Showing Loss of Power.

Name of Firm.	Nature of Work.	Total.	To Drive Shafting.	Per Cent. to Drive Shafting.
Frontier Iron and Brass Works .	Marine engines, &c. . .	25	8	0.32
Baldwin Locomotive Works .	Locomotives .	2500	2000	0.80
W. Sellers & Company (one department)	Heavy machinery	102.45	40.89	0.40
Pond Machine Tool Company .	Machine tools .	180	75	0.41
Yale and Towne Company .	Cranes and locks	135.05	66.81	0.49
Ferracute Machine Company .	Presses and dies	35	11	0.31
Bridgeport Forge Company .	Heavy forgings.	150	75	0.50

This is, of course, when the works are all going full swing.

At Messrs. Richardson's Marine Works, Hartlepool, an electric plant has superseded the transmission by steam pipes and shafting. Mr. Richardson gives the power lost in his works as varying from 25 to 70 per cent. in shafting belts and pulleys. He gives the following table :—

TABLE E.

Showing Power Lost in Shafting Belts, &c.

Engine.	Length of Shafting, in Feet.	No. of Pulleys.	Length of Belt, in Feet.	I.H.P.		Loss Per Cent.
				Loaded.	Light.	
No. 1	370	153	4292	48	17.2	35.8
„ 2	782	113	2263	93.9	23.4	25
„ 3	515	283	3582	44	20.2	46.2
„ 4	571	335	4831	28.9	15	52
„ 5	691	79	1401	56.2	20	35.6
„ 6	381	22	464	75.7	22.8	30
„ 7	117	49	1210	9.3	6.5	69.9
„ 8	242	70	1429	15.6	7.8	50

Messrs. Siemens Brothers converted their works from mechanical to electric transmission, and when complete made a six months' test of the cost per unit for coal, water, stores, wages (stokers, trimmers, drivers, labourers, electrical engineer, and switchboard attendant).

Total cost per B.O.T. unit = 0.59 pence.
Total cost per electric H.P. per hour = 0.44 pence;
or one half-penny per brake horse-power per hour.

The load factor during the time averaged only 28.5 per cent.; that is, of the total power available at the switchboard the average demand was only 28.5 per cent.

A variable crank three-throw pump, driven by a single geared electric motor by Mather & Platt, is of interest.

In electric power stations it is usually most convenient to drive the feed pumps by electric motors, and with pumps hitherto in use, in order to vary the amount of water discharged, resistances have been employed to alter the speed of the motor, and consequently the output of the pump. A large amount of power is wasted in these resistances, and the efficiency of the combination is thereby greatly reduced.

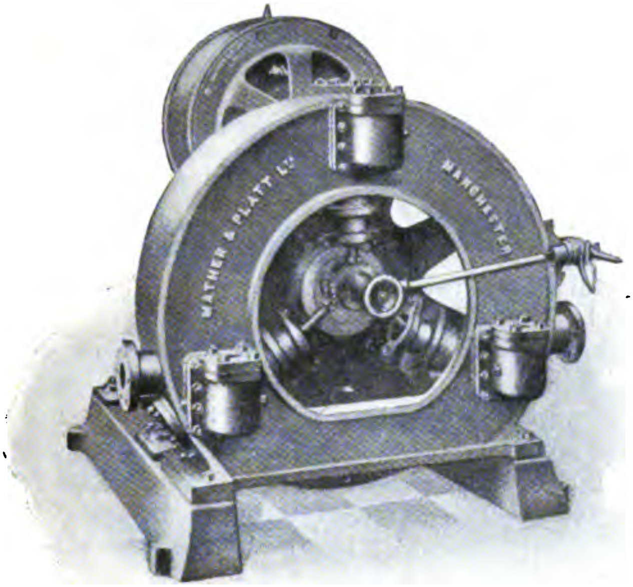


FIG. 177.—Variable Stroke Pump

To obviate this drawback to the efficiency of motor-driven pumps a special type, in which the speed of the motor remains constant, while the stroke of the plungers can be readily adjusted by hand even when the pump is running, is shown in Fig. 177, with the result that the output can be varied from maximum to zero, or *vice versâ*, without any wasteful absorption of power by resistances.

The pump, as constructed, consists of three cylinders mounted radially on a frame at angles of 120° with each other, the plungers being driven from a common crank-pin by connecting rods in the ordinary manner.

Electric Pump

The crank-pin is fixed eccentrically on a disc fitting into a recess in the hub of a toothed wheel, which is driven by a pinion on the shaft of the electric motor.

This recess is itself situated eccentrically to the periphery of the toothed wheel, and thus when the disc is rotated by means of gears situated in the hub, the crank-pin is caused to move in a circle; at one point of this circular course the crank-pin will be at its maximum distance from the centre of revolution of the toothed wheel, and the plungers will therefore perform their full length of stroke; at the opposite point of the circle the crank-pin will be eccentric with the centre of revolution of the toothed wheel, and consequently will have no action on the connecting-rods of the plungers.

An indicator is fixed to the stroke-varying attachment, which shows the length of stroke, and therefore the corresponding output of the pump at the time.

To change the stroke, all that is required is to raise the hand lever until the indicator shows that the desired amount of water is being discharged, whereupon the lever is released.

The lever can be operated directly in the manner described, or from a distance by suitable connections.

We give below a table showing results obtained from tests made on a No. 3 size pump when delivering 3500 gallons per hour, against a pressure of 200 lbs. per square inch.

Test of a 3500-*Gallon Mather & Platt Electrically-Driven Pump.*

Load.	Gallons per Hour, against 200 lbs. per Square Inch.	Combined Efficiency of Motor and Pump.	
		At Constant Speed, with Variable Stroke.	With Constant Stroke, and Speed varied by Insertion of Resistance.
		Per Cent.	Per Cent.
Full	3500	75	75
¾	2625	73	57
½	1750	69	38
¼	875	58	19

The second table shows a comparison of the steam used by four types of pump when delivering the same quantity of water at several loads; and it will be seen that the variable-stroke pump has a great advantage. The figures given for a high-class compound steam-driven pump are the lowest that are guaranteed for a pump just put to work.

Driving Printing Presses

The figures in the last column are based on F. Proctor's paper, read before the British Association, 1898, from which it will be seen that the steam consumption in a pump of this type, which has been in use for some time, is very high.

Output.	Mather & Platt's Variable-Stroke Pump.	Electrically-driven Pump. Variable Speed.	Steam-driven Pump. Best Guarantee for a New Pump.	Proctor's Figures for a Pump after Several Years' Working.
	Lbs. of Steam.	Lbs. of Steam.	Lbs. of Steam.	Lbs. of Steam per Hour.
Full	390	390	740	1100
¾	295	390	560	850
½	210	390	380	650
¼	124	390	200	450

The pounds of steam debited to the electrical pumps are on the assumption that one kilowatt at the motor terminals corresponds to 32 lbs. of steam, the capacities of the pumps being 6400 gallons per hour against 160 lbs. per square inch.

In the full-page plate illustration we have illustrated a direct coupled motor of Holmes type to a two-revolution century press. An electric brake is to be seen hinged to the floor and acting direct upon the flywheel, much in the same style as the Westinghouse tramcar track brake.

For large and important printing presses the Holmes Clatworthy system is used, giving very perfect control over the press.

The main driving motor is of just sufficient size and power to drive the printing machine to which it is geared direct at full speed, and this motor is never called upon to exert more than its full normal output, which is one of the advantages of this system over any other, consequently it works under best and most economical conditions.

The auxiliary motor is of such size and power that it will impart about two or three times the turning effort on the driving shaft that the large motor will at the same speed, thus enabling it to start up the machine from rest easily and without any shock or jerk. The slow or leading-in speed is done entirely by the auxiliary motor, and the machine can be run from two revolutions per minute of the cylinder up to the full speed without the least jerk or undue acceleration.

The machine cannot be started from rest without using the auxiliary motor, though its motion is always transmitted through the large motor shaft. The large motor is thus always in motion before it is called upon to exert any power, which latter it does in consequence more easily than if started from rest.

The two motors are connected to one another by an automatically operated claw clutch. The first motion of the switch causes the clutch to engage; the small motor then starts and runs the machine at its slowest speed. Further motion of the switch causes acceleration in speed. As soon as the large motor takes the load and gains in speed on the small one, the claw clutch, which is of self-releasing type, disengages, and the small motor stops running.

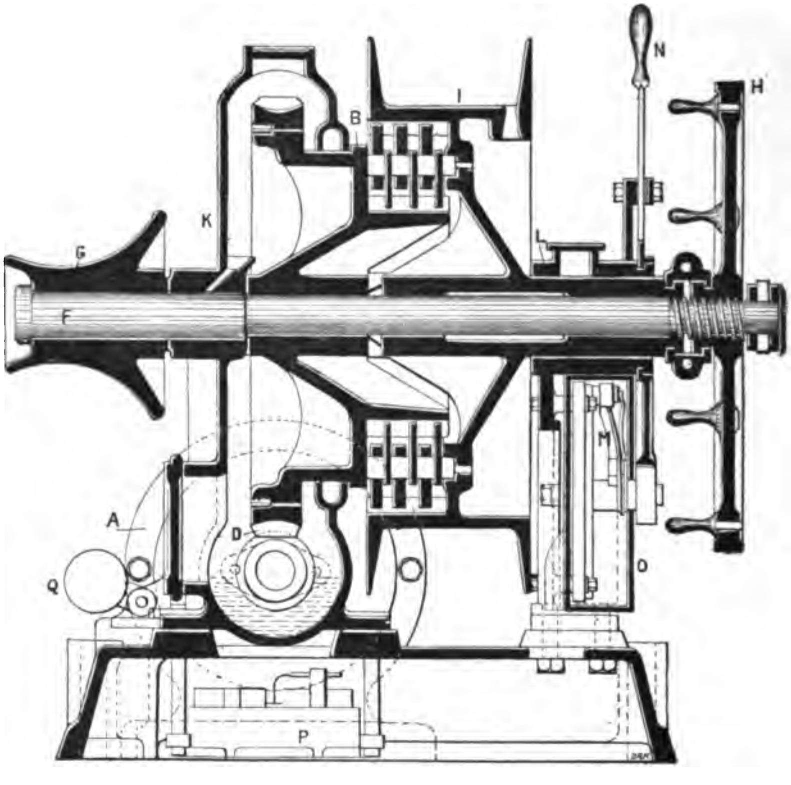


Fig. 178.—Electric Ship Winch

The economy of this method is apparent, as each motor works under its best conditions, and only one is absorbing power at a time excepting for the moment when the change of load takes place. There is thus no waste of current and no overloading, important features which cannot be claimed by any other system. The actual "watts" or energy required to start the machine is only about 10 per cent. of that required for full speed.

Where a machine is required to run at times in two distinct sections, it is convenient and economical to fit two complete electrical equipments, each of which has its own independent controlling apparatus. When the machine is to be run as a whole, the two sections are coupled up mechanically. The controlling switches are also coupled, so that one handle operates both equipments simultaneously. By a special arrangement, a perfect balance of the load is obtained on the two equipments at all speeds, and has proved perfectly satisfactory in practice.

A combined winding drum and winch for use on board steamships is shown in the sectional figure 178. The winch G is fixed to the shaft F, the winding drum is loose on the shaft but can be fixed by the friction clutch B operated by the hand wheel H. M is the starting switch worked by lever N. The motor A is geared by worm and wheel at D, working in an oil bath. Many of these are in use on American ships, but the adoption of motors for heavy work on British ships has been very slow, hydraulic and steam engines still holding place.

In this chapter sufficient instances are given and combinations shown to illustrate the applications of motors in general. Their uses are endless, being so easily adapted to all classes of driving, with high efficiency.

CHAPTER VII

TRANSMISSION AND DISTRIBUTION SYSTEMS

In this concluding chapter the distributing copper mains and conductors are to be considered. The electrical energy delivered from the generators to the switchboard is from thence distributed by mains radiating from the generating station, and in some sense these mains are most important elements in any system. In the first place, they figure largely in the first costs, and afterwards cost much for making connections and extensions. And from the manufacturer's point of view, the business in insulated conductors has been the most profitable of all the branches of electrical engineering in this country.

Secondly, the chief waste of energy goes on in the mains and feeders, and these mains have a very low plant efficiency in municipal and other lighting systems, and this cannot be helped, either by storage or other means, for the cables must be heavy enough to carry the maximum load, with a drop of less than three volts per cent., whereas only for two or three hours in twenty-four are they ever at or near full load.

Of all the energy generated at the station, it is seldom found that more than 75 per cent. of it is paid for; 5 per cent. is used at the station in lighting and motors, and 20 per cent. is wasted in switches, fuses, instruments, and cables—the great bulk of it in the cables.

Alternating current systems are subject to some losses from which the continuous systems are free. These are due to the inductive and capacity effects. In alternating systems the whole cable network has its dielectric charged, discharged, and reverse charged about fifty to sixty times a second; and as the dielectric (or insulation) requires the expenditure of some power to reverse its charge, this loss goes on continually.

All dielectrics are not equally affected in this way; some have less dielectric hysteresis (as this reluctance to reversal is called) than others, so that in alternating systems it becomes a matter of importance to use a dielectric as an insulator which has a small value for hysteresis. Paper is a good insulator with small hysteresis, and hence it is much used, treated with some oils or bituminous materials to render it non-hygroscopic or waterproof.

Loss in Distribution Mains

Some interesting results of tests made at the Croydon supply station by Mr. A. D. Constable and E. Fawsett are instructive on these points. In this case the capacity of the plant is 1250 K.W., and the annual output 1,873,000 units, alternating frequency 60 per second.

In Vol. I. we referred to the necessity for some ready means of testing the conductivity of meters, switches, fuses, and other devices so freely used by electrical engineers in their circuits without much regard to economy. These things are to some extent "necessary evils," and many of them could be taken out of circuit without much inconvenience.

In the case in point the losses in switches, and in the switchboards, was found to be 0.4 per cent., or 10,000 units per annum, which at one penny per unit means £42.

In alternating circuits there are two cable losses besides leakage. Leakage, however, is very small. In this case it was only 14 units per mile on 2000 volt cables. The C^2R losses amount to 150,000 units, or 9.2 per cent. of the output.

The dielectric hysteresis losses were 17,000 units per annum. This is not a large loss, but the pressures are low, and no great lengths are required for the cables.

In the transformer the losses were 173,200 units, and this even when care was taken to switch out many underloaded transformers.

In the electricity meters in the shunt coils required to make them read correctly when the pressure and current curves differ in phase, the losses per annum were 51,500 units. In the series coils of the meters the losses are insignificant.

From the foregoing results it is clear that the alternating system has some very serious inherent faults peculiar to itself; these may be summed up as follows:—

	Units.
Dielectric losses	17,000
Transformer losses	173,200
Shunt Meter Coils	51,500
Total	241,700

None of these losses need occur in a continuous current system.

Part of this installation was changed over to continuous current, using the supply mains which had formerly been in use with the low pressure side of the alternating system, with the result that the total losses were reduced by 40,000 units.

It is a fact that in some alternating electricity supply systems 50 per cent. of the electrical energy generated is wasted in the distribution system.

Standard Cables

As these results become more commonly known and appreciated there can be no doubt that alternating current will be relegated to its proper sphere of action, and therefore the use of high pressure cables will become rare, except on those large electricity in bulk schemes, in which long high pressure lines must be employed for transmission to the long distances. The losses in transmission and distribution are likely to be always considerable, ranging from 15 to 25 per cent. of the output in continuous current systems, and from 25 to 50 per cent. on alternating systems.

The cables themselves have received much attention, and by a sensible action cable makers have agreed upon standard cables for electric light and power networks, and have just issued well drawn up tables likely to meet every requirement, and so we give copies of them here.

The first table gives standard sizes of conductors. The second gives data regarding the dielectric and armouring for low pressure; the third the same for high pressure and certain high pressure concentric cables; and the fourth for extra high pressure cables with three cores.

TABLE I.—*Standard Sizes of Conductors for Electric Supply Mains.*

Nominal Area of Conductors in Sq. Ins.	No. and Diameter of Strands.	Resistance in Standard Ohms per 1000 yds. at 60° F.			Weight in Lbs. per 1000 yds.	
		Calculated.	Maximum Allowable.	Maximum Allowable for Tinned Wires.	Calculated.	Minimum Allowable.
.025	7/ 068	.963	.982	.992	300	294
.050	7/.095	.493	.502	.507	580	568
.050	19/.058	.488	.498	.503	591	580
.075	19/.072	.325	.331	.334	913	896
.100	19/.082	.244	.249	.252	1,182	1,158
.125	19/.092	.194	.198	.200	1,488	1,458
.150	19/.101	.160	.163	.165	1,781	1,745
.150	37/.072	.163	.166	.168	1,776	1,740
.200	37/.082	.125	.128	.129	2,303	2,257
.250	37/.092	.0997	.102	.103	2,900	2,842
.300	37/.101	.0827	.0843	.0852	3,494	3,424
.350	37/.110	.0697	.0711	.0715	4,145	4,062
.400	37/.118	.0606	.0618	.0621	4,772	4,677
.400	61/.092	.0605	.0617	.0623	4.781	4,685
.500	61/.101	.0502	.0512	.0517	5,762	5,647
.600	61/.110	.0423	0431	.0433	6,836	6,699
.600	91/.092	.0405	.0413	.0417	7,134	6,991
.700	91/.098	.0357	.0364	.0368	8,094	7,932
.750	91/.101	.0336	.0343	.0346	8,597	8,425
.800	91/.104	.0317	.0323	.0327	9,115	8,933
.900	91/.110	.0283	.0289	.0290	10,200	9,996
1.000	91/.118	.0246	.0251	.0252	11,740	11,510
1.000	127/.101	.0241	.0246	.0248	11,910	11,672

In concentric cables the mean resistance of the conductors shall be that shown in the table with a maximum allowable variation between the conductors of 5 per cent.

The resistance of each conductor of a twin or multi-core cable will be 2 per cent. higher than that of a single cable having the same area.

Standard Cables

TABLE II.—*Standard Radial Thicknesses of Jute and Paper Dielectric, Lead and Armour for Underground Mains.*

LOW TENSION UP TO 500 VOLTS WORKING PRESSURE.

Test at Works for PAPER 2500 Volts for 15 minutes; when laid and jointed 1000 Volts for 1 hour.
" " JUTE 1500 " " " " " 1000 " "

Nominal Area of Conductors.	Single.		Concentric.			Triple Concentric.				Three Core.	
	Dielectric.	Lead.	Inner Dielectric.	Outer Dielectric.	Lead.	Inner Dielectric.	Intermediate Dielectric.	Outer Dielectric.	Lead.	Dielectric between Conductors, and from Conductors to Lead.	Lead.
Sq. In.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
.025	.08	.06	.08	.08	.07	.08	.08	.08	.08	.09	.08
.050	.08	.06	.08	.08	.08	.08	.08	.08	.09	.09	.09
.075	.08	.07	.08	.08	.08	.08	.08	.08	.10	.09	.10
.100	.09	.07	.09	.09	.09	.09	.09	.09	.10	.10	.10
.125	.09	.07	.09	.09	.09	.09	.09	.09	.11	.10	.11
.150	.09	.08	.09	.09	.10	.09	.09	.09	.11	.10	.11
.200	.09	.08	.09	.09	.10	.09	.09	.09	.12	.10	.12
.250	.10	.09	.10	.10	.11	.10	.10	.10	.13	.11	.13
.300	.10	.09	.10	.10	.11	.10	.10	.10	.13	.11	.13
.350	.10	.09	.10	.10	.12	.10	.10	.10	.14	.11	.14
.400	.10	.10	.10	.10	.12	.10	.10	.10	.14	.11	.14
.500	.10	.10	.10	.10	.13	.10	.10	.10	.15	.11	.15
.600	.11	.11	.11	.11	.13						
.700	.11	.11	.11	.11	.14						
.750	.11	.11	.11	.11	.14						
.800	.12	.12	.12	.12	.15						
.900	.12	.12	.12	.12	.15						
1.000	.13	.12	.13	.13	.15						

The above dielectrics are safe for use at pressures 10 per cent. above their standards.

The dielectric and lead on all conductors, whether mains or pilot wires smaller than .025, shall have the thicknesses given for .025. All intermediate sizes shall have the thicknesses given for the next larger size on the list. Twin cables shall have the same thicknesses as three core.

The allowable variation in radial thicknesses of dielectric and lead at any point is 10 per cent. below the standard minimum thicknesses given in the table, but the mean of the thicknesses shall be at least that specified.

The standards for armouring are as follows:—

For cables below .50-in. diameter over lead, by galvanized steel wires .072-in. diameter.

For cables from .50-in. to .75-in. over lead, by two layers of compounded steel tape each .030-in. thick.

For cables from .76-in. to 2-in. diameter, by two layers of compounded steel tape each .040-in. thick.

Above 2-in. diameter, by two layers of compounded steel tape each .060-in. thick.

The standard thicknesses of Jute serving when applied to diameters less than .50-in. to be .06-in., and for larger diameters .10-inch.

There are two methods for laying underground cables—the drawing-in system and the solid system. In the drawing-in system pipes or ducts of iron, stoneware, or cement are provided, one duct for each cable. Many ducts are at first provided, and the cables afterwards drawn in as required.

The Board of Trade require all high-pressure cables to be sheathed in metal, hence cables are now commonly all lead covered for high pressure, although a cast-iron duct would be a metal sheathing in itself. When iron ducts are used they are laid and jointed in the same way as water-supply pipes, and to enable the cables to be afterwards drawn in, an iron wire is threaded through. Proper precautions are taken against rough edges or obstructions in the pipes, and bends are avoided as much as possible by junction boxes and split-bends, and the pipes where broken by a junction box are bonded for electrical continuity.

Stoneware draw-in conduits are much used also, being jointed by cement. Fig. 179 represents sections of Doulton & Co.'s conduits as laid underground, and Fig. 180 a line of conduits in course of laying down.

TABLE III.—*Standard Radial Thicknesses of Jute and Paper Dielectric, Lead and Armour for Underground Mains.*

Nominal Area of Conductors.	High Tension Concentric. Working Pressure.			Extra High Tension Concentric Working Pressure.								
	2,000 Volts.			3,000 Volts.			6,000 Volts.			10,000 Volts.		
	Dielectric Inner.	Dielectric Earthed Outer.	Lead.	Dielectric Inner.	Dielectric Earthed Outer.	Lead.	Dielectric Inner.	Dielectric Earthed Outer.	Lead.	Dielectric Inner.	Dielectric Earthed Outer.	Lead.
Sq. In.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
.025	.12	.08	.08	.15	.09	.09	.23	.10	.10	.35	.12	.12
.050	.12	.08	.09	.15	.09	.10	.23	.10	.11	.35	.12	.13
.075	.12	.08	.09	.15	.09	.10	.23	.10	.12	.35	.12	.14
.100	.13	.09	.10	.16	.10	.10	.24	.11	.12	.36	.12	.14
.125	.13	.09	.10	.16	.10	.11	.24	.11	.13	.36	.12	.14
.150	.13	.09	.11	.16	.11	.11	.24	.12	.13	.36	.12	.15
.200	.13	.09	.11	.16	.11	.12	.23	.12	.13	.36	.12	.15
.250	.14	.10	.12	.17	.11	.13	.25	.12	.14	.37	.12	.16

The pressure tests of the above cables to be—

Working Pressure.	Tests at Works.	Test when laid and jointed.
2,000 volts.	10,000 volts for 15 minutes.	4,000 volts for 1 hour.
3,000 ,,	12,000 ,, ,, ,,	6,000 ,, ,, ,,
6,000 ,,	20,000 ,, ,, ,,	12,000 ,, ,, ,,
10,000 ,,	30,000 ,, ,, ,,	20,000 ,, ,, ,,

The above dielectrics are safe for use at pressures 10 per cent. above their standards.

The dielectric and lead on all conductors, whether mains or pilot wires smaller than .025, shall have the thicknesses given for 0.25. All intermediate sizes shall have the thicknesses given for the next larger size on the list.

The allowable variation in radial thicknesses of dielectric and lead at any point is 10 per cent. below the standard minimum thicknesses in the table, but the mean of the thicknesses shall be at least that specified.

The standards for armouring are as follows:—

For cables below .50-in. diameter over lead, by galvanised steel wires .072-in. diameter.

For cables from .50-in. to 75-in. over lead, by two layers of compounded steel tape each .030-in. thick.

For cables from .76-in. to 2-in. diameter, by two layers of compounded steel tape each .040-in. thick.

Above 2-in. diameter, by two layers of compounded steel tape each .060-in. thick.

The standard thicknesses of jute serving when applied to diameters less than .50-in. to be .06-in., and for larger diameters .10-in.

Fig. 181 shows a section in which the conduit is slit along the top, so that the top cover may be easily detached from a length in order to gain access to a cable; the cover can then be replaced and cemented down again. This operation has to be made when a service branch is required, as shown in Fig. 183, to insert the end of a junction pipe, Fig. 182. At the drawing-in boxes the ducts terminate in mouthpieces, smooth and tapered as shown in Fig. 184. Bell-mouthed stoneware terminal pieces are also used for iron conduits.

In the solid system the cables are laid in troughs of stoneware, wood, or iron, which are then filled up with bitumen. Bitumen is plastic, and the cable would therefore sink to the bottom of the trough. It is therefore in some cases necessary to use wood supports. Some cover the troughs with a wooden cover; some use tiles and others bricks, and for high pressure iron covers are sometimes used.

Table IV.—*Standard Radial Thicknesses of Jute and Paper Dielectric, Lead and Armour for Underground Mains.*

Nominal Area of Conductors.	High Tension Three-Core. Working Pressure.			Extra High Tension Three-Core. Working Pressures.								
	2,000 Volts.			3,000 Volts.			6,000 Volts.			10,000 Volts.		
	Dielectric Between and Outside.	Dielectric Outer on Star Winding with Centre Earthed.	Lead.	Dielectric Between and Outside.	Dielectric Outer on Star Winding with Centre Earthed.	Lead.	Dielectric Between and Outside.	Dielectric Outer on Star Winding with Centre Earthed.	Lead.	Dielectric Between and Outside.	Dielectric Outer on Star Winding with Centre Earthed.	Lead.
Sq. In.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
.025	.13	.10	.08	.15	.12	.09	.23	.17	.10	.35	.23	.12
.050	.13	.10	.09	.15	.12	.10	.23	.17	.11	.35	.23	.13
.075	.13	.10	.10	.15	.12	.10	.23	.17	.12	.35	.23	.13
.100	.14	.11	.11	.16	.13	.11	.24	.18	.12	.36	.24	.14
.125	.14	.11	.11	.16	.13	.12	.24	.18	.13	.36	.24	.14
.150	.14	.11	.12	.16	.13	.12	.24	.18	.13	.36	.24	.15
.200	.14	.11	.13	.16	.13	.13	.24	.18	.14	.36	.24	.16
.250	.15	.12	.13	.17	.14	.14	.25	.19	.15	.37	.25	.17

The pressure tests of the above cables to be—

Working Pressure.	Test at Works.	Test when laid and jointed.
2,000 volts.	10,000 volts for 15 minutes.	4,000 volts for 1 hour.
3,000 ,,	12,000 ,, ,, ,,	6,000 ,, ,, ,,
6,000 ,,	20,000 ,, ,, ,,	12,000 ,, ,, ,,
10,000 ,,	30,000 ,, ,, ,,	20,000 ,, ,, ,,

The above dielectrics are safe for use, at pressures 10 per cent. above their standards.

The dielectric and lead on all conductors whether mains or pilot wires smaller than .025 shall have the thicknesses given for .025. All intermediate sizes shall have the thicknesses given for the next larger size on the list.

The allowable variation in radial thicknesses of dielectric and lead at any point is 10 per cent below the standard minimum thicknesses given in the Table, but the mean of the thicknesses shall be at least that specified.

The standards for armouring are as follows:—

For cables below .50-in. diameter over lead, by galvanized steel wires .072-in. diameter.

For cables from .50-in. to .75-in. over lead, by two layers of compounded steel tape each .030-in. thick.

For cables from .76-in. to 2-in. diameter, by two layers of compounded steel tape each .040-in. thick.

Above 2-in. diameter, by 2 layers of compounded steel tape, each .060-in. thick.

The standard thicknesses of jute serving when applied to diameters less than .50-in. to be .06-in., and for larger diameters .10-in.

Fig. 185 represents a section of Doulton's stoneware duct and cover for a solid system as used by Siemens Bros. and others. The lid or cover cannot be readily displaced sideways in filling up the trench.

It will be observed that in a draw-in system the cables do not close up the conduits, so that air may flow through and tend to keep the cable and conduit cool, whereas in the solid system the heat generated in the cables is confined by bad conductors of heat, and has to escape by slow conduction only. There is there-

Conduits

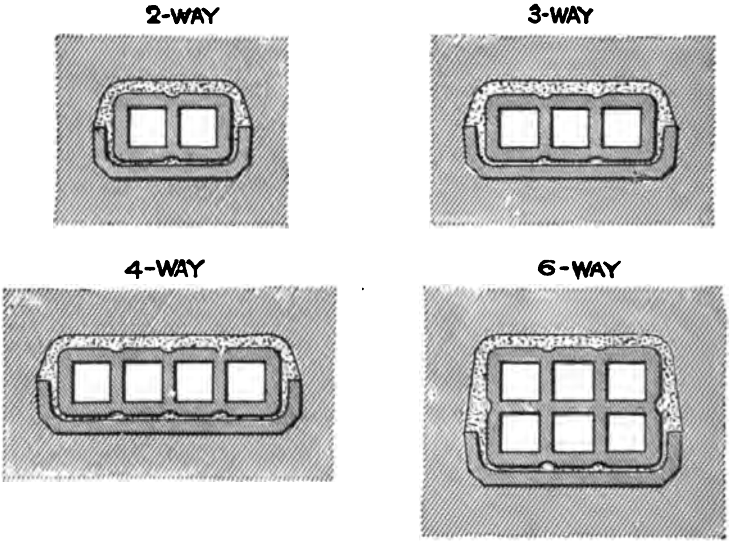


Fig. 179.

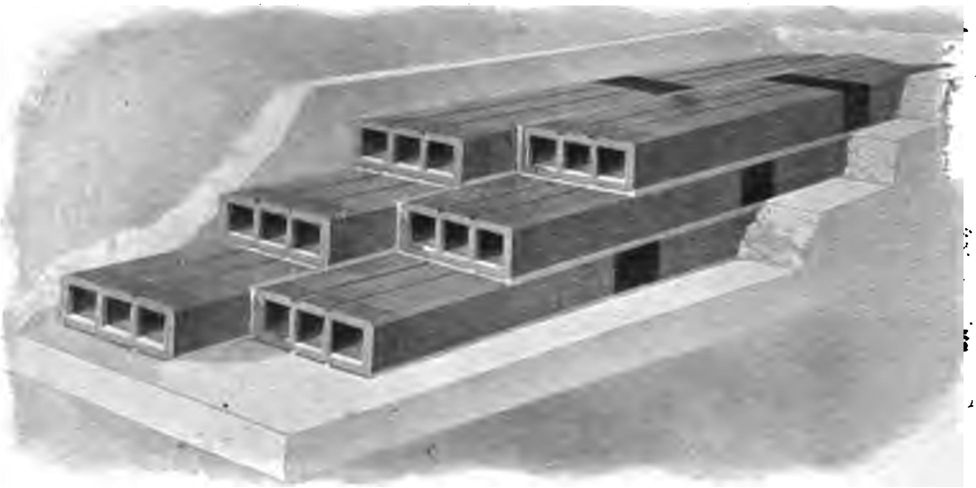


Fig. 180.

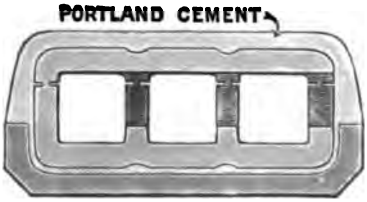


Fig. 181

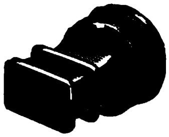


Fig. 182

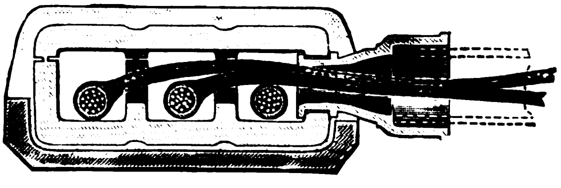


Fig. 183

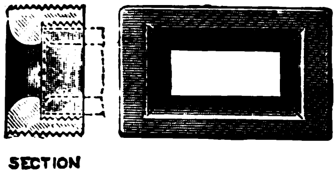


Fig. 184

fore some risk of the heat accumulating and decomposing, or driving off hydro-carbon gases of an inflammable nature which collect in the junction boxes, and may explode.

Explosions in ducts and boxes have been frequently explained by blaming coal-gas leaking from gas mains into electric ducts and being fired by some stray lighted match. No doubt gaseous mixtures have been the cause of many explosions, but it has not always been a coal-gas mixture. In some cases the gases have been electrolytically formed in old systems using a trough with bare strip conductors on stoneware insulators. Explosions have been most frequent, and this is a system one would naturally expect to develop explosive compounds produced by surface currents leaking along insulators. In fact, metallic sodium may be formed by leakage current, and this metal can be fired by a drop of water.

The subject of explosions in underground electric systems has never been properly investigated. Many of the cases have been somewhat mysterious. What actually did explode and what fired the explosive has in most cases only been a matter of conjecture.

The various systems have each their advantages and drawbacks. The old bare strip in troughing was a foolish idea, and was actually laid down in some large cities with disastrous results. The present systems now used in all towns are safe and generally satisfactory, being of course the result of years of experience. Manholes and junction boxes are now thoroughly drained and ventilated, and sub-stations are made roomy, well-lighted, ventilated, and fitted as vaults underground; in fact, some of them are lead-lined to keep out damp. A sub-station is shown in Fig. 190. The cables may be seen coming in through a slot above the switchboards. Various systems of junction boxes are shown in the figures on full-page illustration. Fig. 186 is a plan of a three concentric fourway disconnecting box as made by the B.I.W. Co. Fig. 187 is a vertical section, and Fig. 188 is a plan of a splice box showing a thimble of brass for sweating the two ends together.

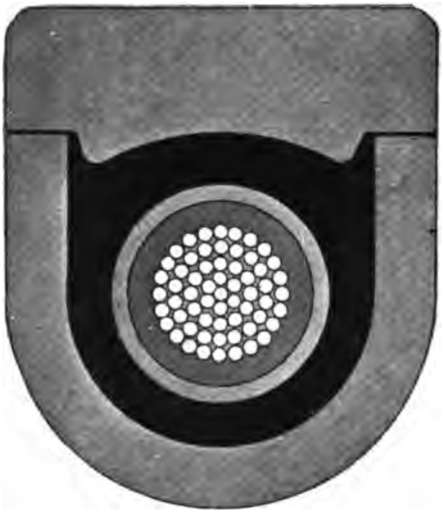


FIG. 185.—Solid System

It is sometimes desirable to reverse the sign of the pressure in a

Junction Boxes

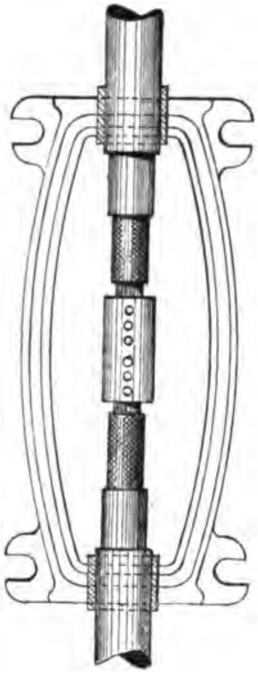
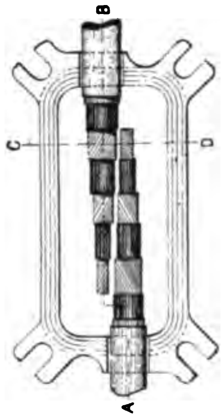


Fig. 188.



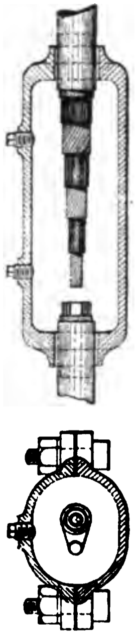


Fig. 189.

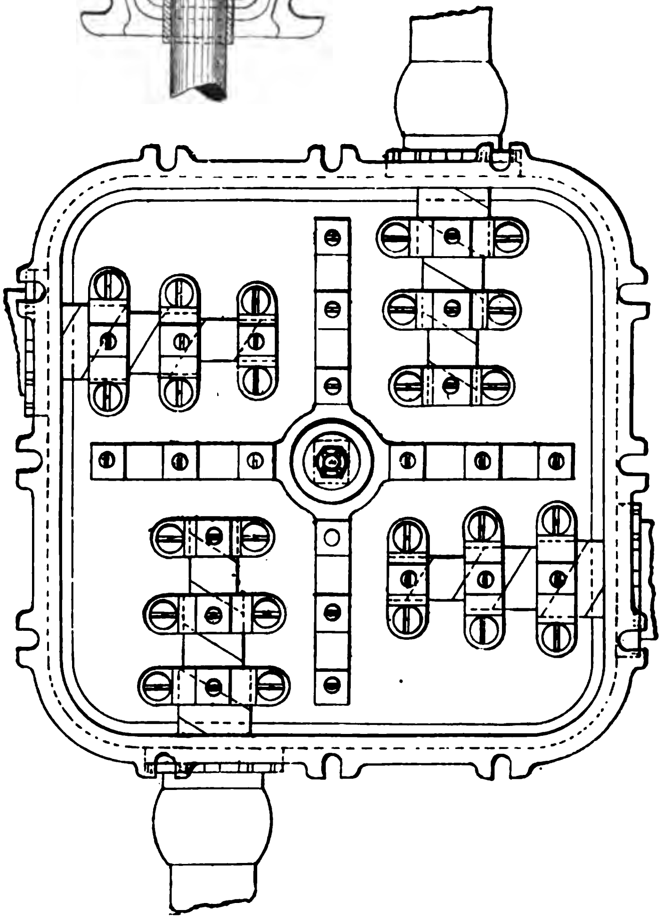


Fig. 186.

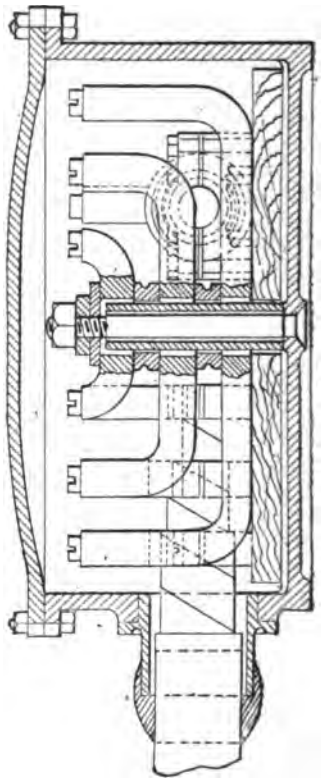


Fig. 187.

three-wire system with concentric cables. In these cases the middle layer of conductor is the middle wire in the system, so that we have a box as shown in Figs. 189, in plan, cross, and vertical section, in which outers of the system are reversed by couplings.

The cable conduits for conduit traction systems are laid on the solid system, as the maximum demand can be known beforehand. The feeders are calculated out, and laid in iron conduits solid, and connected through junction boxes at intervals along the line. Fig. 191 shows a section of the Westinghouse conduit traction system. The trolley conductors are T-irons insulated on brackets; the trolley duct and the feeder ducts being carried on substantial cast-iron cross pieces and the rails tied thereto.

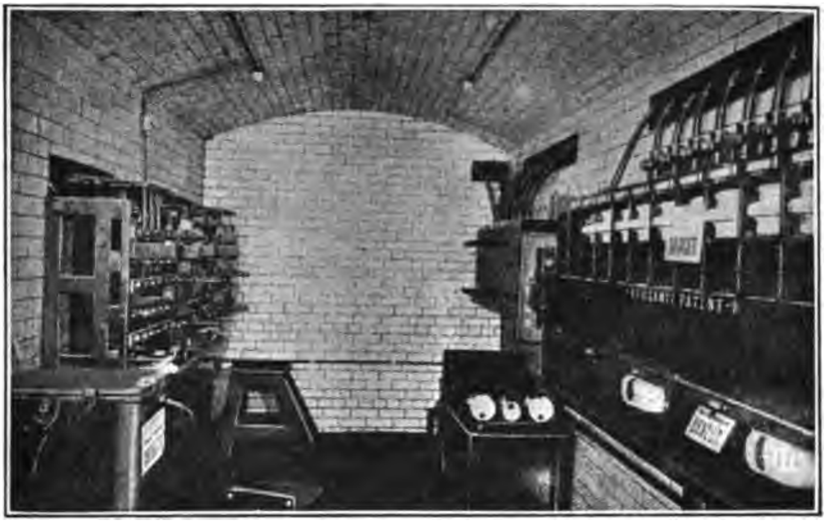


FIG. 190.—Substation

The Lancashire and Yorkshire Branch Railway, Liverpool to Southport, is to be "electrified" by Messrs. Dick, Kerr & Co. The cables for this work are to be of Messrs. Glover & Co.'s armoured paper type, illustrated already in Vol. I., for high pressure.

The working pressure between conductors is 10,000 volts, the centre point of the star being earthed; the pressure to earth is, therefore, only 5780 volts. This earthing of the centre point has considerably reduced the cost of the cable, as a diminished thickness of insulation from earth is permissible under this condition.

The tests on this cable are very formidable indeed, especially when the comparatively small thicknesses are taken into consideration. They are:—

At Works.—30,000 volts alternating between cores (thickness,

.360 inch); 30,000 volts alternating between cores and earth (thickness only .26 inch).

After Laying.—20,000 volts between cores, and between cores and earth, for one hour.

An interesting comparison can be made between this cable and the one supplied to the Manchester Corporation. The latter cable was designed for a working pressure of 6500 volts, centre of star unearthed, and when everybody was under the impression that the Board of Trade rule as to thickness of dielectric applied for all pressures. The thickness between the cores and between the cores and earth is .35 inch. The test pressure on these cables was 14,000 volts. The copper section in each cable is the same, .15 square inch.

The fact that a cable to work at 10,000 volts is actually smaller in dimensions than the Manchester cable working at 6500 volts, at the same time allowing more than twice the pressure tests on the cable, denotes some improvement.

Mains on high-pressure transmission schemes should be materially modified now that cables have been brought to such a pitch of excellence as the above performance denotes. The total quantity of cable to be laid is 32 miles approximately.

The solid system of laying has been adopted, the cables being laid in a wood trough, filled solid, with tile coverings, three cables running in each trough. The cables are to be run on the railway embankment the whole way.

Such a cable as this brings to one's mind the immense power which can be carried a long distance on a small copper conductor, with high insulation. At 10,000 volts, 1 ampere of current would deliver about 13 horse-power, or for 1 ampere in each of the three conductors a carrying power capacity of about 50 horse-power.

The schemes for generating and distributing electricity in "bulk" has been from time to time alluded to in these volumes. They do not differ much except in dimensions from large municipal stations and distribution. No new developments have occurred to give them any advantages over existing schemes. The usual powers have been granted by Parliament over certain areas in Britain, in which companies may generate and distribute electrical energy in bulk. These are marked out on the map as published by the *Electrical Review* of London, and shown in figure by thick black lines. Some of the companies have made a start, and others are preparing.

As an engineering undertaking, the establishment of these large schemes is beyond all doubt quite feasible, and no difficulties from a scientific or practical engineering point of view can be foreseen. The question is, in fact, a commercial and financial one, and in all its aspects very wide-reaching. And large amounts of capital are required to begin operations, so that the first step is to obtain investors to support the undertakings.

After that, the demand for the new commodity in bulk will depend of course on the price per unit charged for it. At present, light and power users obtain electrical energy when they want it on a large scale by establishing a generating plant of their own, smaller consumers buying from Corporations.

The possible customers at first should be small communities, small towns where tramways and lighting could be run without the cost of a station and the expense of running it.

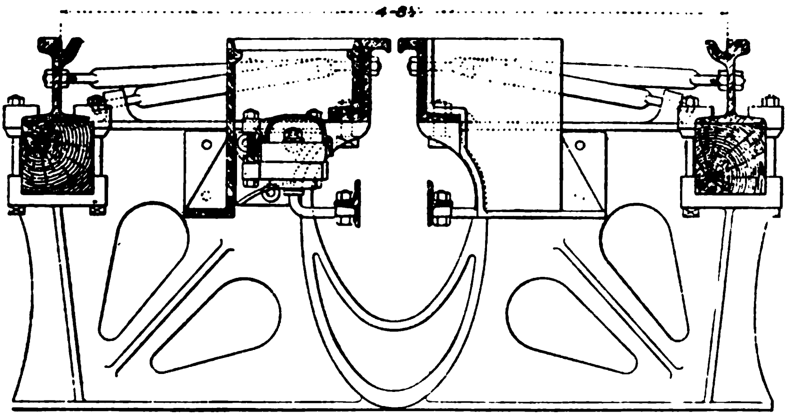


FIG. 191.—Traction Conduit

The second class of customers should be factories in which mechanical transmission of power is changed over to electrical by numerous motors taking the place of belts, pulleys, and shafting, or steam piping. A third class should be for tramways to work from villages to towns and connect outlying districts.

In many factories the cost of electric transmission, even if somewhat greater than the supply by an isolated plant, would not deter the owners from changing over from mechanical to electrical transmission, and giving up their boilers and engines, if the supply were delivered at a proper pressure and in proper form for use on motors, for the saving in power would more than compensate for the extra charge, and relieve the millowner of all trouble about boilers and engines and their attendant costs. It is a fact that most users of power have a feeling that their power plant is a source of anxiety, and they would do without it very gladly if a substitute could be found at no more cost.

Now the point upon which this question turns has already been discussed herein, and it is a simple one. If the electric-power is delivered to one or two large motors displacing one or two large steam-engines in a factory, the electrical energy will require to be very cheap indeed, about one halfpenny per unit, to show any advantage, for the simple reason that none of the great losses in the transmission of the power in the factory would be in the slightest degree reduced by the change.

In such a proposition the question is only this: What is the price of one B.H.P. on the engine shaft compared with the price of a B.H.P. on the motor shaft? and the inquiry extends no further.

On the other hand, if the electrical energy is delivered by motors to the machines to be driven without any intervening mechanical transmission gear, then a higher value can be set upon the electrical energy. For the question to decide the matter is: What is the cost per B.H.P. delivered and transmitted mechanically, compared with that delivered to the machines by electric transmission? In most cases of one machine one motor transmission electrical energy at 1 to 1.5 pence per unit would show advantages in costs, and these taken with other incidental advantages, such as saving of wear and tear and attendance upon the discarded transmission gearing, would in most cases insure the adoption of the supply in bulk.

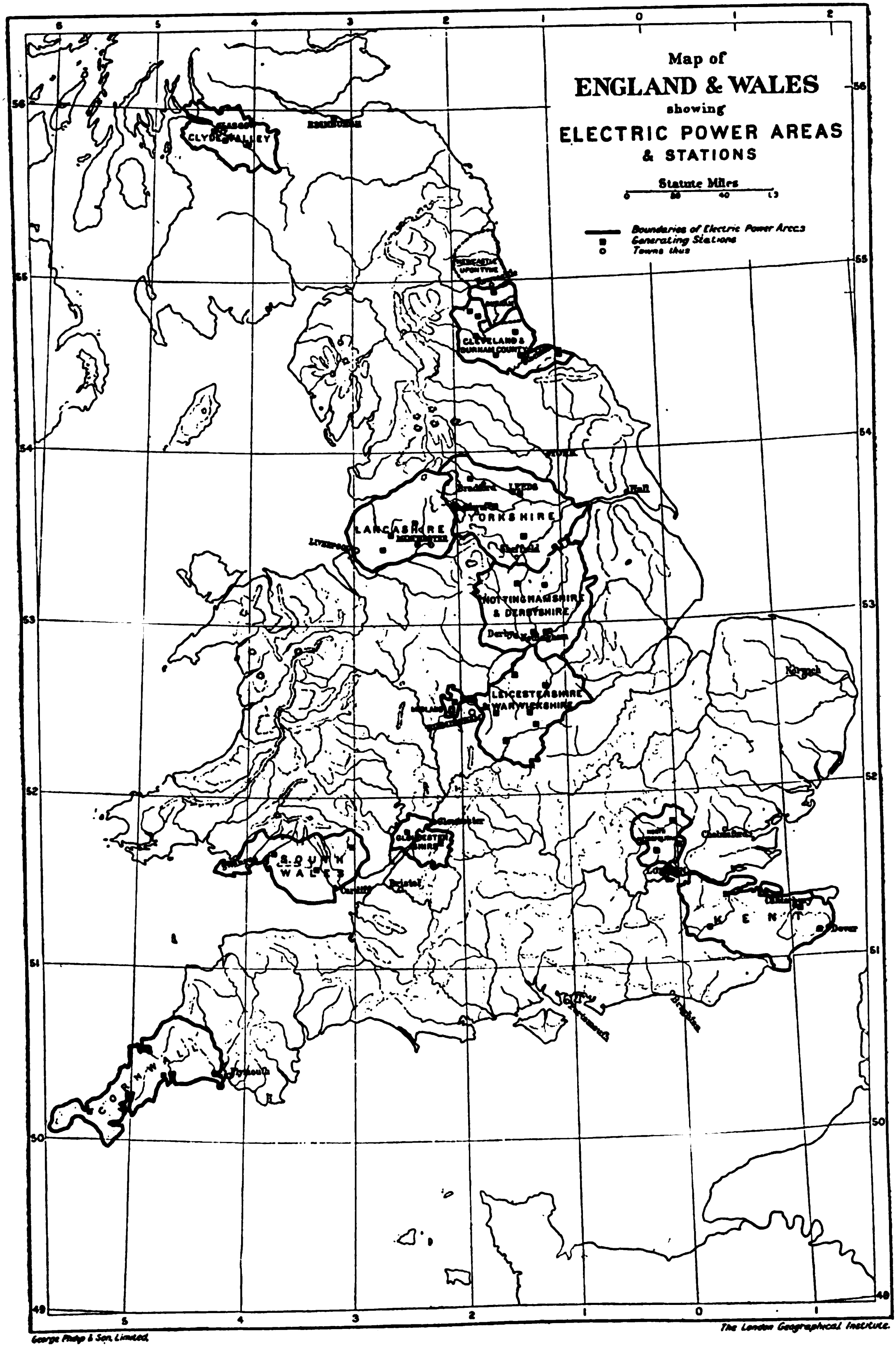
At the generating stations, if these are properly situated on cheap land, unrestricted, there may be some substantial advantages over the isolated plant in the matters of cheap fuel and cheap labour and free water, all of which might reduce the works cost of production.

The gas-engine using producer-gas and producing ammonia sulphate as a bye-product would reduce the fuel cost to a small value. Such a generating station is partly a chemical and partly an electrical energy producing concern.

The engineering of these large stations is a very important question, so that it may be allowable to venture an opinion that, as at least 70 per cent. of the work to be carried out is purely mechanical, the designs and their execution should be in the hands of a mechanical engineer of great experience and skill, assisted by an electrical engineer. The success of the plant will depend much more upon the good mechanical engineering of it, than upon the electrical engineering.

The generators in all likelihood best suited will be three-phasers with step-up transformers at the station.

The long transmission lines will present the most difficult problems in order to reduce the losses therein. In fact the cost of energy per unit delivered to the consumer will depend more upon the economy of the transformers, converters, transmission and


Map of
ENGLAND & WALES
showing
ELECTRIC POWER AREAS
& STATIONS
Statute Miles
0
20
40
60
Boundaries of Electric Power Areas
Generating Stations
Towns thus
CLYDE VALLEY
EDINBURGH
NEWCASTLE UPON TYNE
CLEVELAND & DURHAM COUNTY
YORK
Hull
Bradford
LEEDS
YORKSHIRE
LANCASHIRE
MANCHESTER
LIVERPOOL
Sheffield
NOTTINGHAMSHIRE & DERBYSHIRE
Derby
Nottingham
LEICESTERSHIRE & WARWICKSHIRE
Norwich
Gloucester
GLOUCESTERSHIRE
Chelmsford
LONDON
SOUTH WALES
Cardiff
Bristol
KENT
Dover
Portsmouth
Brighton
CORNWALL
Plymouth
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53
52
51
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George Philip & Son Limited
The London Geographical Institute

FIG. 192

distribution system, than upon the works cost per unit at the switchboard. It is from the dynamo terminals to the consumers terminals where the schemes require the attention of the highest electrical engineering skill to make them a success.

At the consuming points the current will pass through step-down transformers and rotary converters to alternating and continuous current at low pressures for use.

This is a very interesting process, and one much beloved by foreign engineers, this conversion, transforming, reconversion, and retransforming. But it is very questionable if it is the best practice to follow; what it saves with one hand it gives away with the other to a large extent.

To save copper we have to use extra high pressure; to use extra pressure we must introduce transformers and converters, composed largely of copper, and in which losses occur which go a long way to counterbalance the gains made by the extra high pressure used.

It is a very serious question whether continuous currents would not be in the end the better system; this system would be free of capacity effects and transformer losses, and the plant efficiency and power factors would be considerably higher.

The choice of the system, however, will not be made on recommendations on scientific grounds, but upon commercial considerations, influenced by the fact that polyphase systems have already been introduced on a large scale in some places with success; and that more often determines the adoption of a system than its actual fitness for the case in point at the time.

The continual changing over in municipal plants proves this to be true, for it shows that many plants were put in which were not at all the best fitted for the town or city. Many plants put in under skilled supervision have been found quite unsuitable and abandoned before they were ten years old.

However, the movement towards the supply in bulk is one which will increase electrical engineering business in the country to a large extent. And it is to be earnestly hoped that by good electrical and mechanical engineering, and the liberal support of investors by capital, that the first stations established will prove successful in every respect.

The electric-motor business especially must go on increasing rapidly under a cheap supply of electrical energy; it is now becoming the best business in electrical installation. Continuous, single-phase, and polyphase motors are not likely to be superseded in the future by any improvements; they have arrived at a high stage of efficiency and reliability. Whatever changes may be made by future discoveries in producing electrical energy the dynamo as a generator may go, but it as a motor will remain always.

In the next volume to follow this one the lighter branches of electrical engineering will be treated, also signalling, telegraphing, telephony, and wireless transmission across space, and other apparatus of interest to a large number of people not engaged in heavy electric light and power work.

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